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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1953 ANNUAL MEETING

AT

HARVARD UNIVERSITY

CAMBRIDGE, MASSACHUSETTS

January 22–23–24, 1953

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AMERICAN PHYSICAL SOCIETY

1953 ANNUAL MEETING, JANUARY 22–24, 1953

THE **1953 Annual Meeting of the American Physical Society** will be held at Cambridge, Massachusetts, in the buildings of Harvard University, on Thursday, Friday, and Saturday, January 22, 23, and 24, 1953. This will be the first Annual Meeting of the Society held at Cambridge since we desisted from the old usage of having joint meetings in holiday week with the American Association for the Advancement of Science. Columbia University has been the host of the Annual Meeting for ten years running; its staff will appreciate a well-earned vacation, and the amazing dimensions of this meeting show that the members of the Society have already appreciated the opportunity of assembling among the scientific community of the Boston area. Harvard University is rich in lecture rooms to contain our sessions, and will accommodate the American Association of Physics Teachers—hereinafter to be denoted by AAPT or "the Association"—as well as ourselves. The Chairman of the Local Committee is R. W. Hickman; to him and to his many colleagues we express our thanks in advance for the heavy labors they have undertaken. The President of the Society would like to have this designated as "the New York Meeting in Cambridge." So be it; the Metropolitan area will be glad to extend itself to include the community of Cambridge.

Rooms in the following **hotels** were set aside for our members by the Convention Bureau (of the Boston Chamber of Commerce): Commander and Continental, in Cambridge; Parker House, Sheraton Plaza, Somerset, Statler, and Touraine in Boston. Those who neglected the opportunity for early reservation accorded by the summons card are advised to repair the omission immediately. Write to the hotel of your choice, say that you are a member of the Society, and intimate your willingness to be put up in some other hotel if that one is full.

Fast subway trains run to Harvard Square from the station in Boston denoted as "Park Street Under." Denizens of the Parker House and the Touraine use this station; those of the Statler, Sheraton Plaza, and Somerset use, respectively, the stations at Arlington and Boylston, Dartmouth and Boylston, Massachusetts Avenue and Boylston, and take eastbound trains to Park Street. People living at the Cambridge hotels require no guidance to the University region, but all will be advantaged by the map which appears on page 64 of this Bulletin.

The **registration desk** will be set up in the spacious foyer of the new Allston Burr Hall of the General Education Programme. All members and guests are asked to register, and frequently to consult the nearby bulletin boards for notice of messages. Payment of the usual **registration fee of one dollar** will be requested.

The **joint ceremonial session** of our Society and the Association will be held, as is the custom, on Friday afternoon beginning at two. First, the President-Elect of the Society will take the chair, and President J. H. Van Vleck will deliver his Retiring Presidential Address, entitled "Two Barrier Phenomena." The President of the AAPT will then succeed to the chair, and the Oersted Medal of the Association will be conferred upon R. M. Sutton, who will respond with a speech under the title "The Heritage of a Physics Teacher." The session will be concluded with the eleventh Richtmyer Memorial Lecture of the AAPT, the lecturer being the recent Nobel laureate, E. M. Purcell, and the title of the lecture "Nuclear Magnetism."

Seventeen invited papers on a variety of topics appear in the general programme: the speakers are Francis Bitter, P. W. Bridgman, H. G. Dehmelt, R. H. Dicke, E. L. Hahn, G. R. Harrison, J. A. Hornbeck, G. F. Hull, Sr., P. D. Johnson, A. F. Kip, Gunnar Lindström, H. V. Neher, L. S. Osborne, E. C. Pollard, James Rainwater, Julian Schwinger, and Alexander Zucker.

Brookhaven National Laboratory provides a Symposium (Session EB) on its new accelerators, present and projected.

Our **Division of Electron Physics** and our **Division of Fluid Dynamics** have each of them a Symposium; the reader is referred to later pages of this Bulletin for the names of the speakers and the titles of their papers.

Two hundred and ninety-eight contributed papers are distributed among twenty-nine sessions. The vastness of the programme and the pressure of preparation made it necessary to enforce to the letter the By-Law of the Society which excludes abstracts that are received after the deadline day. Some of the sessions are too long; the Secretary chose to make them so rather than to prevent some of our members from attending the speeches of Messrs. Van Vleck, Sutton, and Purcell.

The **banquet of the Society and the Association** will be held on Friday evening at seven in the Ballroom of the Hotel Continental. The after-dinner speakers will be Vice-President and Provost J. A. Stratton of M.I.T.; and the Oliver E. Buckley Solid State Physics Prize will be conferred on W. Shockley. The price will be $3.25. Fill out and send in the form on the inside back cover page of this Bulletin; the hotel must know in advance of the meeting approximately how many will attend the dinner. Uncalled-for and unpaid-for tickets will be released to the first comers after 2:00 P.M. on Friday.

The **Oliver E. Buckley Solid State Physics Prize,** to be awarded for the first time at the banquet of this meeting, has been endowed by Bell Telephone Laboratories in honor of its Past President. The sum of one thousand dollars, together with a diploma, will be presented to the chosen individual who will have been "adjudged to have made a most important contribution to the advancement of knowledge in Solid State Physics within the five years immediately preceding the award." Twenty-five such prizes will be awarded in due time—one a year in principle, though there is provision for holding over to a later date the prize corresponding to any year. After the lapse of twenty-five years, the endowment becomes the unconditional property of the American Physical Society. The Secretary regrets that his own connection with the donor organization makes it unseemly for him to praise this donation in the language that it deserves. Let others do so.

To return to the theme of **eating**: luncheon-arrangements will be described at the registration desk. In advance it is announced that a limited number of places will be available in the Harkness Commons of the Graduate Student Center—but only for those who will get there at 12:30 P.M. *sharp*. Tickets for these may be bought at 95 cents, so long as the supply holds out, at the registration desk.

Tea will be served on Friday, after the ceremonial session, in the Gordon McKay Laboratory of Applied Science. This is the very new, and in fact unfinished, building which is to house a part of the research work of the Division of Applied Science of Harvard University. Our members are asked not to infer its future resources from its present state of incompletion.

The **Harvard cyclotron, computation laboratory, and anechoic chamber** may be seen on Friday afternoon after the ceremonial session. Being near the Gordon McKay Laboratory, they can be enjoyed before or after the tea.

The **Geophysics Research Directorate invites** the members of the Society to visit its laboratories at 415 Summer Street, South Boston, on Friday morning. These laboratories are devoted to the physics of the atmosphere from the lowest levels to the maximum heights of rocket and radio penetration, and to other fields of terrestrial physics. It will be appreciated if members will notify the Directorate of their intention to pay this visit. Information as to how to get to the laboratories will be available at the registration desk.

The American Institute of Physics will operate a **Placement Service** Register in the Gordon McKay Laboratory of Harvard University. Employers and applicants should report to the Register upon arrival at the meeting. Descriptions of open positions and requests for registration forms should be sent to the Institute, 57 East 55 Street, New York 22, New York. In order to insure their inclusion at the Register, registrants' completed registration forms and employers' descriptions of open positions must be received at the Institute office by January 12, 1953.

Sigma Pi Sigma will hold its midwinter luncheon on Friday at 12:30 P.M. at the Commander Hotel. Tickets for members of the Society will be on sale at the registration desk.

The **Business Meeting of the American Physical Society** will be held on Friday morning at nine: Sanders Theatre has been optimistically chosen as the place. The officers of the Society often look back to the old days when there was never more than one scientific session at a time, and the Business Meeting was intercalated into the middle of one of these, so that the members who had come for the scientific papers hardly dared to walk out

on it. It is hoped that on the 23rd of January there will be many early risers among our members.

The **Council of the American Physical Society will meet** on *Wednesday* (January 21) at 2:00 P.M. in Room 213 of Pierce Hall.

Cocktails will be served on Saturday afternoon from four to six at the Faculty Club of M.I.T. on the sixth floor of the Sloan Building at 50 Memorial drive. Buy tickets ($1.50) at the registration desk no later than Friday afternoon. Those who attend may dine at the Club.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society not later than Friday, January 16. The titles of such as are accepted will be announced on a blackboard near the registration desk, and the papers will be given under the usual ten-minute rule at the end of Session EA. The abstracts will not be published.

Prospective meetings of the Society are scheduled to be held in Durham, North Carolina, on March 26–28; in Washington, D. C., on April 30, May 1, and 2; in Rochester, New York, on June 18–20; and in Albuquerque, New Mexico, on September 2–5.

General Rules Relating to Papers

The time allowed for the oral presentation of a contributed paper is ten minutes at most. The time allowed for the oral presentation of each invited paper is stated, with rare exceptions, in the Bulletin.

When two or more contributed papers are submitted by the same author, or by more than one author but with the same name appearing first in the by-line, all but one are placed on the "supplementary programme." For each paper on this programme a session is indicated, at the end of which it may be offered; but the Chairman of the session may limit it to fewer than ten minutes, or may read it by title.

Titles and abstracts of the papers contributed to the 1953 Annual Meeting are printed hereinafter. They will reappear in *The Physical Review* exactly as they stand in this Bulletin. Errata will be printed on a following page of *The Physical Review* if received not later than Friday February 6 by Miss Ruth Bryans, American Institute of Physics, 57 East 55th street, New York 22, New York. Do not send in the abstract marked with corrections: write out the corrections in the form "instead of . . . read. . . ." Do not add new material.

Speakers must retrieve their lantern slides before leaving the hall in which these were shown. The Local Committee is under no obligation to save or to return them, and is earnestly advised not to accept this burden.

Karl K. Darrow, *Secretary*
American Physical Society
Columbia University
New York 27, New York

Here Is the Summons Card for the 1953 Washington Meeting

This notice supplants the customary summons card for the 1953 Washington meeting.

The dates of the meeting will be Thursday April 30, Friday and Saturday May 1 and 2, 1953.

The hotels in which rooms have been set aside for our members are the Shoreham, Wardman Park, Raleigh and Roger Smith. Act quickly to reserve your room, writing to the hotel of your choice and mentioning the Society; reservation for two in a room, or expression of willingness to share a room, will often help you in getting accommodations. The Shoreham and Wardman Park are again the generous providers of halls for scientific sessions; it would be a nice gesture to make either of them your first choice.

Deadline Will Be Friday, March Thirteenth

An abstract may not be longer than 200 words or the equivalent thereof. In reckoning equivalence, a "display" formula (having a line to itself) is equated to 40 words, each line in a table to 10 words, each footnote to 10 words. Send two typed copies of your abstract to the address below. Confine each abstract to a single page; abstracts spread over two pages cost the editors a lot of trouble; an abstract too long to be readily typed on a single page is too long to conform to our rules. Abstracts which reach this office after Friday, March thirteenth, will not be accepted. Do not overestimate the ability of the postoffice to rush your abstract to its destination, and do not expect a special-delivery stamp to undo the effects of late posting.

Karl K. Darrow, *Secretary*
American Physical Society
Columbia University, New York 27, New York

EPITOME OF THE 1953 ANNUAL MEETING

(Personal names are those of invited speakers.)

Thursday Morning

A. Hornbeck; semiconductors. Fogg.
B. Dicke; microwave spectroscopy. Pierce.
C. Nuclear and electronic scattering. Paine.
D. Pi-mesons. Geology Lecture Room.
E. General physics. Allston Burr, A.
EA. Cryogenics; post-deadline papers. Jefferson 250.
EB. New accelerators at Brookhaven: Green, Snyder, Blewett. Sanders.

Thursday Afternoon

F. Kip, Hahn, Dehmelt; quadrupole resonance. Allston Burr, B.
G. Rainwater, Osborne; mu-mesons and neutral mesons. Sanders.
H. Solid-state physics (nonmetals). Paine.
I. Apparatus of nuclear physics. Fogg.
J. Neutron physics, I. Pierce 110.
JA. Various topics in theoretical physics. Allston Burr, A.

Friday Morning

Business Meeting of American Physical Society: Sanders, 9:00 A.M.
K. Bitter; magnetic resonance; molecules. Pierce 110.
L. Neher; cosmic rays, I. Jefferson 250.
M. Neutron physics, II. Paine.
N. Johnson; luminescence and photoconductivity. Allston Burr, A.
NA. Theoretical nuclear physics. Geology Lecture Room.
O. Bridgman, Harrison, Hull, Pollard. Sanders.

Friday Afternoon

P. Joint ceremonial session of APS and AAPT; Van Vleck, Sutton, Purcell. Sanders.
Tea at the Gordon McKay Laboratory.

Friday Evening

Banquet of APS and AAPT; Stratton; presentation of the Oliver E. Buckley Solid State Physics Prize.
Hotel Continental, 7:00 P.M.

Saturday Morning

Q. Business Meeting and Symposium of Division of Electron Physics: O'Day, Kantrowitz, Nergaard, Livingston. Sanders.
R. Cosmic rays, II. Allston Burr, B.
S. Lindstrom; radioactive nuclei, I. Allston Burr, A.
SA. Theoretical physics, including high energy scattering. Pierce Hall, 110.
T. Ferromagnetics and ferroelectrics. Paine.
U. Fluid Dynamics. Geology Lecture Room.
UA. Molecular-beam experiments; various topics in nuclear physics. Fogg.

Saturday Afternoon

V. Symposium of Division of Fluid Dynamics. Paine.
VA. Metals. Pierce 110.
W. Zucker; reactions of transmutation; photoelectric effect. Fogg.
WA. Schwinger; theoretical physics, atomic and molecular. Sanders.
X. Biophysics; high-polymer physics; liquids. Geology Lecture Room.
Y. Electromagnetic and electron physics. Allston Burr, A.
Z. Radioactive nuclei, II; fission. Allston Burr, B.

PROGRAMME

THURSDAY MORNING AT 10:00

Fogg Museum

(M. H. HEBB presiding)

Invited Paper

A1. Trapping of Injected Carriers in Semiconductors. J. A. HORNBECK, *Bell Telephone Laboratories.* (30 min.)

Semiconductors

A2. Theory of Diffusion of Injected Carriers in a Semiconductor of Mixed Conductivity Type. HARVEY BROOKS, *Harvard University.*—The one-dimensional small signal solution for the diffusion of an indical pulse of holes injected into a semiconductor at $t=0$, $x=0$ is derived in a simple way. This solution is applicable for arbitrary equilibrium carrier densities n_0 and p_0. It is shown that to an excellent first approximation the excess electron and hole densities n_1 and p_1 are equal, and per unit carrier injected, $p_1(x,t)=(4\pi Dt)^{-\frac{1}{2}}\exp[-t/\tau]\times\exp[-(x-\mu E_0 t)^2/4Dt]$, where $D=(n_0+p_0)/(n_0/D_p+p_0/D_n)$, $\mu=(n_0-p_0)/(n_0/\mu_p+p_0/\mu_n)$, $1/\tau=r(n_0+p_0)$, and r=specific recombination rate. This solution reduces to the familiar solution for the Haynes experiment when $n_0\gg p_0$. The second approximation can also be evaluated and will be shown to be entirely negligible.

A3. Chemical Equilibria Involving Electrons as Independent Chemical Entities in Impurity Semiconductors. HOWARD REISS, *Bell Telephone Laboratories.*—The thermodynamic effects resulting from the ionization of donor and acceptor impurities in semiconductors have been investigated theoretically. It can be shown, for example, that deviations from Henry's law should be apparent in the vapor pressures of such impurities above their solid solutions with semiconductors out to very high dilutions. It is possible to calculate an activity coefficient (whose measurement furnishes information on the Fermi level of the electrons in the solution) and, also, to formulate a limiting law. In addition, it can be demonstrated, using the methods of statistical mechanics, that over certain experimentally realizable ranges of conditions the electrons in such solutions behave operationally as chemical individuals; so much so that the activity coefficient, mentioned above, can be computed from the law of mass action. Certain details concerning the relation between the Fermi level and the free energy per electron are discussed carefully.

A4. A High Impedance Field-Effect Silicon Transistor. G. L. PEARSON, *Bell Telephone Laboratories.*—A unipolar field-effect transistor which exhibits many of the characteristics predicted in Shockley's theoretical analysis[1] has been constructed. The device is a silicon $p-n$ junction[2] so designed that the conductivity of a thin layer of high purity material can be modulated by the transverse electric field across the junction. The conductivity of the n-type material is high. In a typical unit, junction capacitance as a function of reverse bias follows a square law relationship corresponding to a hole density of 10^{14} cm^{-3}. This value checks the measured conductance through the relation $\sigma=ne\mu_h$, where μ_h is the hole mobility. The shapes of drain current *versus* drain voltage characteristics with gate voltage as a parameter are as predicted[1] with pinch-off at 25 volts and exhibit good saturation at higher drain voltages. Characteristics similar to vacuum tubes can be obtained with the following typical values: $r_{in}=16$ megohms, $r_{out}=0.25$ megohms, $C_{in}=3.2$ $\mu\mu f$, $\mu=5$, and $g_m=20$ micromhos. A power gain of 30 db was obtained through the voice frequency range with a noise figure of 26 db at 1000 cycles.

[1] W. Shockley, Proc. Inst. Radio Engrs. **40**, 1365 (1952).
[2] E. Buehler and G. K. Teal, Phys. Rev. **87**, 190 (1952).

A5. n-type Conduction on p-type Germanium Surfaces. W. L. BROWN AND W. SHOCKLEY, *Bell Telephone Laboratories.*—Evidence for a layer of electron conduction (rather than hole conduction) at the surface of p-type germanium has been found in studies of $n-p-n$ transistors. The transistors studied showed aging effects when reverse biases were applied to the junctions. After aging it was found that currents could be passed between emitter and collector even though both were biased at a volt or more reverse with respect to the base. These currents are incompatible with electron diffusion through the base layer. They suggest there is a separate conducting channel connecting emitter and collector. It is proposed that aging produces a positive surface charge on the base region. The positive charge induces a layer of n-type conductivity just below the surface. This layer provides an essentially ohmic connection between the emitter and collector regions. The observed channel conductance depends on the junction bias in a way to be expected from such a model. Capacity measurements provide further evidence for the channel. When the specimen is so treated that a channel is present, an added capacity is found between the emitter and collector connected together and the base. The magnitude of the capacity is consistent with the proposed model.

A6. Microwave Determination of Electrical Properties of Germanium. JAMES M. GOLDEY AND SANBORN C. BROWN, *M.I.T.*—A solution of Maxwell's equations in a resonant cavity has been obtained by Hsieh[1] which can be used to determine the electrical properties of semiconductors. Microwave measurements in the 10-cm region have been made on germanium[2] using standard techniques.[3] Thin rods of germanium are mounted coaxially in a cylindrical cavity and standing wave measurements as a function of frequency are made in the line. Seventy-seven measurements were made on both p and n samples. The resistivities varied from intrinsic to 7.0 ohm-cm. Sample diameters ranged from 0.020 inch to 0.035 inch, corresponding to a variation in the ratio of cavity diameter to sample diameter from 150 to 85. Conduction electrons in an ac field affect the dielectric coefficient. The magnitude of this effect has been calculated from Boltzmann transport theory. The correction, dependent upon the effective mass, is applied to the experimental results and K_s is obtained.

[1] H. T. Hsieh, Tech. Rept. 2, Solid State and Molecular Theory Group, M.I.T. (to be published).
[2] Kindly supplied by Dr. W. Shockley and associates of Bell Telephone Laboratories.
[3] S. C. Brown and D. J. Rose, J. Appl. Phys. **23**, 711 (1952).

A7. Pressure Dependence of Resistivity of Germanium. WILLIAM PAUL, *Harvard University.*—The pressure dependence of the resistivity of a sample of n-type germanium having

a room temperature resistivity of 35 ohm-cm has been measured from 0 to 30 000 atmospheres at temperatures of 23°, 42°, 60°, and 76°C. The pressure apparatus was that previously developed and used by Bridgman. At the highest temperature the sample remained nearly intrinsic over the entire pressure range and, assuming constant mobility, it was found that the energy gap increased almost linearly with pressure over the entire range. The slope of the graph gives $dE_G/dp = 5.5 \times 10^{-12}$ ev per dyne per cm². This is in fair agreement with results obtained by Miller and Taylor and with the value deduced from the hole and electron mobilities in the deformation potential theory. The results at the lower temperatures give an *S*-shaped curve of $\ln\rho$ *vs* p, similar to that previously reported by Bridgman.

The slopes of all 4 curves above 15 000 atmospheres are in quite close agreement. This slope also agrees with that measured by Bridgman for this sample and for much less pure samples at room temperature in the same pressure range. The value is also fairly close to the initial slope of the intrinsic curve. This result is surprising, since a plot of $\ln\rho$ *vs* T^{-1} confirms that at the lower temperatures the sample is not intrinsic in the high pressure range.

A8. Comparison of Copper-Doped Germanium with Heat Treated Germanium. F. J. Morin and J. P. Maita, *Bell Telephone Laboratories.*—It has been suggested[1] that copper is one impurity responsible for thermally produced acceptors. This idea has been substantiated by a comparison of acceptor levels in germanium pulled from a copper-doped melt, germanium into which copper has been diffused with heat treatment, and heat-treated germanium to which no copper was intentionally added.[2] The Hall effect and conductivity[3] have been measured on samples prepared in the three ways described. In all samples, an acceptor level was found at about 0.040 ev, which, presumably, is due to copper atomically dispersed in the germanium lattice. Lower lying acceptor levels were found in some samples. Hall mobility for all samples showed an abnormally rapid drop at low temperatures. The lower lying levels and abnormal mobility are not understood at the moment.

[1] C. S. Fuller and J. D. Struthers, Phys. Rev. **87**, 526 (1952); W. P. Slichter and E. D. Kolb, Phys. Rev. **87**, 527 (1952).
[2] Heat-treated samples prepared by C. S. Fuller.
[3] Measured on apparatus built by P. P. Debye.

A9. The Effect of Surface States in Diode Rectification Theory. M. Cutler, *Hughes Aircraft Company.*—The theory of surface states, as presented by Bardeen,[1] predicts that the surface potential barrier is practically constant and is independent of the contact potential difference at the metal contact, if there is a high density of surface states. Exactly the same argument applies for the effect of an imposed bias. The barrier potential therefore should be constant, with the added voltage being supported by a change in the electric double layer composed of the surface charge in the metal, and the surface charge associated with the surface states of the semiconductor. This differs from the generally accepted rectification theory for germanium and silicon diodes, which requires the surface potential barrier to vary directly with the bias. A new diode theory is derived which takes into account this effect due to surface states. It predicts that the fraction γ of the current carried by minority carriers will increase with increasing forward bias, thus helping to explain injection. Other implications of these results for rectifier theory are discussed.

[1] J. Bardeen, Phys. Rev. **71**, 717 (1947).

A10. The Hall Effect in Titanium Georgiana Scovil, *Bryn Mawr College* (introduced by W. C. Michels).—The Hall coefficient for titanium has been measured by a direct current method and found to be equal to $+(2.8 \pm 0.9) \times 10^{-11}$ VM³/Awb for a temperature of about 100°C. This may be most simply explained by assuming that holes as well as electrons contribute to conduction. Combining resistivity data with the Hall coefficient and using a free electron model, the densities of electrons and holes have been estimated to be 0.3×10^{27} electrons/M³ and 7.5×10^{27} holes/M³. These densities in turn have been used to determine the depth of the bottom of the 4*s* band below the Fermi level and a value of 0.12 ev has been obtained.

A11. The Photo-Hall-Voltaic Effect.* Charles F. Wahlig and Park H. Miller, *University of Pennsylvania.*—The Schottky-Mott theory of the barrier layer rectification which was previously extended[1] with respect to the action of light absorbed in the barrier layer is further extended with respect to the coexistence of a Hall voltage, and it is shown that the light and the Hall voltage interact producing a third external voltage. This effect has been detected experimentally, using a 70 cps Hall current, a 60 cps magnetic field, and constant illumination of the barrier contact region by a carbon arc lamp. The photo-Hall voltage proves to be of the same frequency as the detected Hall voltage (10 cps) and orders of magnitude larger using strong illumination. The theory agrees with the experimental findings that the spectral response is strong in the ultraviolet, the photo-Hall voltage tends to saturate with increasing magnetic field, and the photo-Hall voltage is of the same frequency as the Hall voltage for constant illumination. The theory predicts that the photo voltage, the Hall voltage, and the photo-Hall voltage can be measured simultaneously by proper frequency channeling if a shuttered light source is used.

* The research described in this report was supported by the Air Force.
[1] K. Lehovec, Phys. Rev. **74**, 463 (1948).

Thursday Morning at 10:00

Pierce Hall, 110

(M. W. P. Strandberg presiding)

Invited Paper

B1. Excitation of Superradiant States: A New Technique for High Resolution Microwave Spectroscopy. R. H. Dicke, *Princeton University.* (30 min.)

Microwave Spectroscopy

B2. The Rotational Spectrum and Molecular Structure of Cyclopropyl Chloride.* B. P. Dailey, *Columbia University.*—The $J = 2 \rightarrow J = 3$ and $J = 3 \rightarrow J = 4$ transitions for $C_3H_5Cl^{35}$ and $C_3H_5Cl^{37}$ have been studied and in addition the $1_{01} \rightarrow 2_{11}$ transitions have been observed. The following rotational constants and moments of inertia have been derived from the

spectral data: for $C_2H_3Cl^{35}$: $A=17{,}695.1$ Mc, $B=3905.4$ Mc, $C=3622.4$ Mc, $I_A=47.41\times10^{-40}$ gcm², $I_B=214.81\times10^{-40}$ gcm², $I=231.60\times10^{-40}$ gcm²; for $C_2H_3Cl^{37}$: $A=17{,}930$ Mc, $B=3810.0$ Mc, $C=3540.5$ Mc, $I_A=46.79\times10^{-40}$ gcm², $I_B=220.21\times10^{-40}$ gcm², $I_C=236.97\times10^{-40}$ gcm². The following quadrupole coupling constants for Cl^{35} were obtained from an analysis of the hyperfine structure patterns:

$$eQ\frac{\partial^2 V}{\partial Z}=-55.3 \text{ Mc}, \quad eQ\frac{\partial^2 V}{\partial X}=33.9 \text{ Mc}, \quad eQ\frac{\partial^2 V}{\partial y}=16.4 \text{ Mc}.$$

The structural conclusions and their significance to valence theory will be discussed.

* Assisted by the Signal Corps and the Research Corporation of New York.

B3. Constants of Centrifugal Distortion.* D. KIVELSON AND E. B. WILSON, JR., *Harvard University.*—The relation between the constants of centrifugal distortion in polyatomic molecules and vibrational force constants has been reinvestigated. The distortion constants depend linearly upon the inverse force constants and bilinearly upon the derivatives with respect to internal displacement coordinates of the components of the inertia tensor. These derivatives are usually quite difficult to obtain since the internal displacement coordinates are subject to six translation-rotation conditions. However, it has been shown that the derivatives of the moments of inertia are independent of these conditions, while the derivatives of the products of inertia only depend upon the rotation conditions. With these results as a basis, rules have been derived for obtaining the desired derivatives with respect to the more common internal displacement coordinates. It has also been shown that group theory can give some knowledge of the distortion constants if the molecule has any symmetry.

* Supported by ONR.

B4. Preliminary Analysis of the Microwave Spectrum of Ethylenimine. T. E. TURNER, VERNA C. FIORA, W. M. KENDRICK, AND B. L. HICKS, *Aberdeen Proving Ground.*—Sixteen absorption lines have been observed in the K-band microwave spectrum of the asymmetric rotor C_2H_4NH. Nine of these lines have been assigned to Q branch transitions in the pure rotation spectrum of this molecule. For the electric moment parallel to the b axis, the sub-branch wing $J_{k,2}\rightarrow J_{k+1,1}$ where $k=J-2$ has been assigned for $J=2$ up to $J=7$ as well as one transition $5_{4,1}\rightarrow5_{5,0}$ belonging to another wing of the same sub-branch. For the molecular model assumed, a small component of the electric moment lies along the c axis and two allowed transitions, $5_{4,1}\rightarrow5_{5,1}$ and $8_{6,2}\rightarrow8_{7,2}$ have been assigned. The values $a-c=(9352\pm1)$ mc/s and $\kappa=+0.6700\pm0.0002$ lead to a consistent set of assignments. Theoretical relative intensities agree with the measured values. Stark effect patterns were observed and are in agreement with the assignments, although the Stark structures are not completely resolved for the higher J transitions. Hyperfine structure has been resolved for the low J transitions but as yet has not been studied. The eigen-values used in the energy level calculations were obtained from an EDVAC computation of the asymmetric rotor table. Use is being made of the ORDVAC in determining the molecular parameters from the observed data. These applications of high speed computing machines to asymmetric rotor analysis will be discussed briefly.

B5. The Microwave Spectrum and Structure of Thionyl Fluoride.* R. C. FERGUSON AND E. B. WILSON, JR., *Harvard University.*—Seventy lines in the microwave spectrum of the asymmetric rotor thionyl fluoride, SOF_2, have been measured in the region 16 950 to 35 500 megacycles/second. From the observed Stark effect patterns, three pure rotational transitions were identified: $1_{01}\rightarrow2_{11}$ at 33 685.69, $1_{10}\rightarrow2_{20}$ at 33 957.43, and $1_{11}\rightarrow2_{21}$ at 34 201.22 mc. From these $J=1$ to 2 transitions the following reciprocal moments of inertia were calculated: 8614.75, 8356.98, and 4923.55 mc. These assignments were confirmed by computing the $0_{00}\rightarrow1_{10}$ transition, which was then found at 16 971.75 (predicted 16 971.73 mc). These data lead to structural parameters somewhat different from the electron diffraction values previously published.

* Work supported in part by the ONR.

B6. S-Band Spectrum of HDO.* S. WEISBAUM, Y. BEERS, AND G. HERRMANN, *New York University.*—A Stark-modulated microwave spectroscope has been constructed for operation in the S-band region. The rotational absorption spectrum of the asymmetric rotor HDO was observed in the region from 2100–4400 Mc/sec. The following lines were found: 2399 Mc/sec, 2836 Mc/sec, 2991 Mc/sec, and 2888 Mc/sec. The first three have been tentatively identified as the $6_1\rightarrow6_2$, $12_{-1}\rightarrow12_0$, and $9_0\rightarrow9_1$ transitions, respectively, while the last one is unidentified as yet. The frequencies were measured to an accuracy of about 3 Mc/sec with an absorption wave meter. Since six other "a-type" transitions have been observed in HDO,[1,2] an attempt was made to fit all the known data to a single centrifugal distortion formula. The frequencies, calculated in this way, were found to agree with the observed frequencies within a few megacycles.

* Supported by the ONR.

[1] C. H. Townes and F. R. Merrit, Phys. Rev. **70**, 558 (1946).
[2] M. W. P. Strandberg, J. Chem. Phys. **17**, 901 (1949); private communication.

B7. Pressure Broadening of O_2 Lines in the Millimeter Wavelength Region.* J. O. ARTMAN† AND J. P. GORDON, *Columbia University.*—Additional data on low and high pressure oxygen absorption has confirmed and extended previously reported results.[1] The average value of the line breadth parameter $\Delta\nu/P$ for lines of rotational quantum number $K=1$ to $K=19$ is 1.94 Mc/mm Hg. β, the ratio of N_2-O_2 broadening to O_2 self-broadening is 0.90 ± 15 percent. The absorption of O_2 in dry air at pressures of $\frac{1}{4}$, $\frac{1}{2}$, and 1 atmos has been compared with computations based on the Van Vleck-Weisskopf line shape formula. With the $\Delta\nu/P$ value of 1.94 Mc/mm Hg, a good fit to the experimental data was obtained with β equal to 0.75. The line broadening has been attributed to exchange and polarizability interactions.[1] Interactions of the form $\cos^2\theta/Y^N$, which yield half-widths depending inversely on K when treated by adiabatic broadening theories,[2] are shown to result in breadths essentially independent of K when treated by the more appropriate diabatic broadening theory.[3]

* Work supported jointly by the Signal Corps and ONR.
† Now at Project Lincoln, Massachusetts Institute of Technology.
[1] J. O. Artman and J. P. Gordon, Phys. Rev. **87**, 227 (1952).
[2] M. Mizushima, Phys. Rev. **83**, 94 (1951); Phys. Rev. **84**, 363 (1951).
[3] P. W. Anderson, dissertation, Harvard University (1948); Phys. Rev. **76**, 647 (1949).

B8. Zeeman Effect in Rotational Spectra of Asymmetric-Rotor Molecules.* B. F. BURKE AND M. W. P. STRANDBERG, *M.I.T.*—The theory of rotational molecular magnetic moments given by Eshbach and Strandberg[1] has been applied to the study of the Zeeman effect in microwave rotational spectra of asymmetric-rotor molecules. The perturbation energy is determined by a set of quantities G_{ij}, whose transformation properties are known, since the product with the appropriate moment of inertia, I_jG_{ij} behaves like a tensor under rotation. Furthermore, the first-order Zeeman effect is a function of the diagonal elements only. Consequently, if an isotopic form exists such that the principal axes of G_{ij} coincide with those of the moment of inertia tensor, only three quantities are required to specify completely the Zeeman effect for all isotopic species of the molecule. The three common forms of the water molecule, H_2O, D_2O, and HDO, were chosen to verify the theory. Measurements of five rotational lines of HDO, and of the single known lines of H_2O and D_2O, were made with a

high resolution microwave spectrograph. The observed splitting factors were used to calculate G_{ij} for all three molecules, and the results were utilized to confirm the identification of uncertain lines in the water vapor spectrum.

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and the ONR.
[1] J. R. Eshbach and M. W. P. Strandberg, Phys. Rev. **85**, 24 (1952).

B9. The Influence of a Magnetic Field on the Microwave Dielectric Constant of a Liquid Crystal. E. F. CARR AND R. D. SPENCE, *Michigan State College.*—We have studied the complex dielectric constant of the liquid crystal phase of *para*-azoxyanisole in the presence of a static magnetic field at a wavelength of 2 cm. The loss factor depends on the temperature and the intensity and orientation of the static magnetic field. If the static field is orientated parallel to the electric field in the wave-guide absorption cell, it produces a marked decrease in the loss factor. If the static magnetic field is perpendicular to the electric field, it produces very little effect. Associated with the large change in the loss factor in the parallel case there is a small change in real part of the complex dielectric constant. These effects extend through out the liquid crystal phase (118°C–135.8°C) but disappear at the transition to the normal liquid phase.

THURSDAY MORNING AT 10:00

Paine Hall

(GREGORY BREIT presiding)

Scattering

C1. Proton-Proton Scattering at 435 Mev.* W. E. MOTT AND R. B. SUTTON, *Carnegie Institute of Technology.*—The differential proton-proton elastic scattering cross section is being measured using the external proton beam of the 450-Mev Carnegie Institute of Technology synchrocyclotron. Protons which emerge from the cyclotron without the aid of deflecting or focusing mechanisms are collimated before and after being deflected by an auxiliary magnet. The intensity 10 m from the machine is of the order of 10^6 cm^{-2} sec^{-1}; the energy is approximately 435 Mev as indicated by rough absorption measurements. A coincidence technique is used to count the scattered and recoil protons. Cross sections are obtained from polyethylene-carbon differences. The beam is monitored by integrating the current of an argon filled ionization chamber. Preliminary results have been obtained for scattering angles of 90°, 65.3°, and 36.3° in the center-of-mass system. The cross sections at these angles are in the ratio 1:1.04:1.19. Although the errors arising from counting statistics are of the order of 5 percent, the possibility of other experimental errors has not yet been eliminated.

* Supported in part by the AEC.

C2. Neutron-Proton Scattering Near 180° at 94 Mev.* W. SELOVE, K. STRAUCH, F. TITUS, *Harvard University.*—The angular distribution of $n-p$ scattering has been measured with neutrons of 94 Mev effective energy, at six angles between 155° and 180° in the center-of-mass system. This angular region is of particular interest because of the disagreement which various published measurements show. Our results show relative cross sections at 180°, 170°, and 160°, of 100, 95, 81 (statistical error ~2½ percent, angular resolution ~3°), in substantial agreement with measurements by Fox[1] (90 Mev) and by Randle *et al.*[2] (156 Mev), and in disagreement with the measurements of Hadley *et al.*[3] (90 Mev).

* Supported by the ONR.
[1] R. H. Fox, USAEC report UCRL-867 (1950).
[2] Randle, Taylor, and Wood, Proc. Roy. Soc. (London) **213**, 392 (1952).
[3] Hadley, Kelly, Leith, Segré, Wiegand, and York, Phys. Rev. **75**, 351 (1949).

C3. Proton-Proton Scattering in the Interference Minimum Region.* D. I. COOPER,† D. H. FRISCH, AND R. L. ZIMMERMAN, *M.I.T.*—Proton-proton scattering at 90° in the center-of-mass system has been measured as a function of energy from 350 to 450 kev, and the interference minimum between Coulomb repulsion and nuclear singlet *S*-wave attraction has been located at 385±3 kev. The bombarding protons were accelerated by a small pressurized electrostatic generator. Their energy was measured by a generating voltmeter calibrated in terms of the nearby $Li^7(p, \gamma)$ and $F^{19}(p, \gamma)$ resonances. The protons were scattered in charcoal-purified hydrogen differentially pumped, and were counted by a proportional counter operating in the scattering gas at the scattering chamber pressure of 1.5 cm Hg. The current was measured with a Faraday cup. Neither absolute current, pressure, nor geometry had to be known to locate the minimum. The value obtained gives a phase shift $\delta = 14°35' \pm 4'$ lying on the best shape-independent fit to the higher energy data of Worthington, Findley, and McGruer,[1] and agreeing with the low energy data of Heydenburg and Little.[2]

* Supported by joint program of ONR and AEC.
† Now at Bell Telephone Laboratories, Murray Hill, New Jersey.
[1] Worthington, Findley, and McGruer, Phys. Rev. **87**, 223 (1952).
[2] Quoted by Yovits, Smith, Hull, Bengston, and Breit, Phys. Rev. **85**, 540 (1952).

C4. Total Neutron Scattering Cross Sections of Polyethylene and Carbon at 1.32 Mev.* C. L. STORRS† AND D. H. FRISCH, *M.I.T.*—The total cross sections of polyethylene and graphite have been measured at a neutron energy of about 1.32 Mev. The effective energy of the main group of neutrons from the reaction $Li^7(p, n)$ on the Rockefeller generator was determined by centering on the broad total scattering resonance in oxygen at an energy measured as 1.320±0.003 Mev in terms of the $Li^7(p, n)$ threshold. The lower energy group of neutrons was almost completely rejected by high bias on the proton-recoil proportional counter used as the detector. In one run the beam current was raised to keep the same counting rate in the detector when the scatterer was interposed as when the neutrons were unattenuated, eliminating rate effects on detector sensitivity associated with such a steep bias curve. The long counter neutron intensity monitor thus ran at low and high rates, alternately. The monitor sensitivity was proved to be almost rate independent by testing the superposition of counting rates of two RaBe sources. The results of the few well-understood runs give $\sigma CH_2 = 9.56 \pm .04$ and $\sigma C = 2.21 \pm .02$ barns at the energy of this oxygen resonance.

* Supported by joint program of the ONR and AEC.
† Now at A.N.P., General Electric Company, Lockland, Ohio.

C5. Neutron-Deuteron and Proton-Deuteron Scattering in the *S*-wave Region.* R. L. ZIMMERMAN, D. I. COOPER, AND D. H. FRISCH, *M.I.T.*—The total $n-D$ scattering cross-section was measured at neutron energies of from 100 to 550

kev, and the differential $D-p$ scattering cross section was measured at deuteron energies of from 200 to 900 kev. These experiments use essentially the apparatus described in the two previous abstracts. A comparison of S-wave neutron-deuteron[1] and proton-deuteron[2] scattering data is made as follows: Using the observed thermal scattering lengths[3] and epithermal cross sections,[4] the $n-d$ doublet and quartet effective ranges are determined from the present $n-d$ data in the shape-independent approximation. The doublet effective range thus obtained can be interpreted in terms of a static potential only if it has a repulsive core. These scattering lengths and effective ranges are then converted to the $p-d$ case assuming charge-symmetry and some knowledge of the wave function inside the range of forces. The predicted $p-d$ cross section will be compared with the observed $p-d$ cross section on assumptions of various $p-d$ static interactions.

* Supported by joint program of the ONR and AEC.
[1] Nuckolls, Bailey, Bennett, Bergstralk, Richards, and Williams, Phys. Rev. **70**, 805 (1946); Walt and Adair, private communication.
[2] R. F. Taschek, Phys. Rev. **61**, 13 (1942); Freier, Stratton, Brown, Holmgren, and Yarnell, Phys. Rev. **86**, 593 (1952).
[3] Hurst and Alcock, Can. J. Phys. (January, 1951); Gordon, Ph.D. thesis, Washington University (1950); E. O. Wollan and C. G. Shull, Phys. Rev. **73**, 830 (1948).
[4] E. Fermi and L. Marshall, Phys. Rev. **71**, 666 (1947); Rainwater, Havens, Dunning, and Wu, Phys. Rev. **73**, 733 (1948).

C6. The Interaction of 14-Mev Neutrons with Protons and Deuterons.* A. H. ARMSTRONG, J. C. ALLRED, AND L. ROSEN, *Los Alamos Scientific Laboratory.*—Nuclear emulsions in conjunction with a neutron collimator have been utilized to measure the differential cross section as a function of angle for the elastic scattering of monoenergetic 14-Mev neutrons by protons and by deuterons. The angular region investigated corresponds to angles in the center-of-mass system between 48° and 154.5° for neutrons scattered by protons and between 46° and 176° for neutrons scattered by deuterons. The $n-p$ scattering data are consistent with isotropic scattering in the center-of-mass system and are in excellent agreement with the data of Barschall and Taschek.[1] The $n-d$ elastic scattering data are strongly anisotropic.[2,3] The shape of the angular distribution of the neutrons elastically scattered by deuterons may be inferred from the differential cross sections in millibarns for the following laboratory angles: 2°, 435±28; 10°, 342±27; 20°, 78±9.3; 30°, 38±4.2; 40°, 59±5.2; 50°, 104±9.0; 60°, 136±12; 65°, 142±14. Strong evidence for the reaction $d(n, 2n)p$ was found, and an attempt to determine the energy and angular distribution of the disintegration protons was moderately successful.

* Work performed under the auspices of the AEC.
[1] H. H. Barschall and R. F. Taschek, Phys. Rev. **75**, 1819 (1949).
[2] J. Coon and R. F. Taschek, Phys. Rev. **76**, 710 (1949).
[3] Griffith, Remley, and Kruger, Phys. Rev. **79**, 443 (1950).

C7. Angular Distributions of 21 Mev Protons Elastically Scattered by Various Nuclei. R. V. NEIDIGH AND B. L. COHEN, *Oak Ridge National Laboratory.*—Angular distributions of 21-Mev protons elastically scattered by about 15 nuclei ranging from beryllium to thorium have been measured using the internal beam of the ORNL 86-inch cyclotron and the methods described in Abstract .[1] The measurements are at 2° intervals from 10° to 25° and at 4° intervals from 25° to 110°. The results show all the characteristics of shadow scattering. There are two minima followed by maxima for the lightest elements, one secondary maximum for intermediate elements, and only a monotonic decrease with increasing angle for heavy elements. The maximum and minimum for aluminum occur at the same angles as in the calculations of LeLevier and Saxon,[2] but they are sharper. If instead of the raw data, the ratio of the observed to Rutherford cross section is plotted *vs* angle, at least two minima and maxima occur for every element, and the shift in their positions can be traced from element to element through the periodic table. The angle at which they occur follows approximately an $A^{-\frac{1}{3}}$ dependence until they reach the small angle region where Coulomb scattering predominates. The maxima occur at $\theta(r/\lambda)\simeq 2.0$, 4.5, 7.5, and 11, while the minima occur at $\theta(r/\lambda)\simeq 3.0$, 6.1, and 10.

[1] Abstract unspecified by author.
[2] R. E. LeLevier and D. S. Saxon, Phys. Rev. **87**, 40 (1952).

C8. Inelastic Scattering of Protons and Deuterons from B^{10}.† C. K. BOCKELMAN, C. P. BROWNE, A. SPERDUTO, AND W. W. BUECHNER, *M.I.T.*—Protons and deuterons accelerated in the MIT–ONR generator have been used to bombard thin targets of enriched B^{10} evaporated on thin films of Formvar. Inelastically scattered groups were observed at 90 degrees with the annular magnetic spectrograph. Preliminary measurements[1] of the energies of the proton groups have been extended and refined, yielding the following values, ±10 kev, for the B^{10} levels: 0.717, 1.740, 2.152, 3.585, 4.771, 5.105, 5.159 Mev. Of the levels below 4 Mev, the 0.72, 2.15, 3.58 states scattered deuterons. No deuteron group that could be attributed to the 1.74-Mev level was observed for bombarding energies of 6.0, 6.9, and 7.6 Mev. At 6.9 Mev, an upper limit of 0.04 may be set for the ratio of the intensity of the scattering from the 1.74-Mev level to that of the weakest neighboring level. Considering the results reported in the following abstract, it seems reasonable to ascribe the absence of this deuteron group to the operation of an isobaric spin-selection rule.

† This work has been supported by the joint program of the AEC and ONR.
[1] Buechner, Browne, Elkind, Sperduto, Enge, and Bockelman, Phys. Rev. **87**, 237 (1952).

C9. Inelastic Scattering of Protons and Deuterons from N^{14} and Li^6.† C. P. BROWNE, C. K. BOCKELMAN, W. W. BUECHNER, AND A. SPERDUTO, *M.I.T.*—Using the equipment noted in the preceding abstract, a thin Nylon film was bombarded at energies of 7.0 and 7.6 Mev. Inelastic proton and deuteron groups from the levels in N^{14} at 3.95 Mev[1] and proton groups from the level at 2.31 Mev[1] were observed. No deuteron group from the 2.31 level was seen. The Li^6 target was prepared by depositing enriched LiCl on a thin film of collodion and Formvar. At a bombarding energy of 7.4 Mev, proton and deuteron groups from the level at 2.18 Mev and a proton group from the level at 3.58 Mev was observed. No deuteron group from the 3.58 level was seen. These measurements and the one described above indicate three examples of levels in light nuclei which do not scatter deuterons. While charge symmetry of nuclear forces may account for these phenomena, the positions of these levels may indicate that the more inclusive assumption of charge independence is justified and that the reactions are forbidden because isobaric spin must be conserved.[2]

† This work has been supported by the joint program of the AEC and ONR.
[1] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **24**, 320 (1952).
[2] R. K. Adair, Phys. Rev. **87**, 1041 (1952).

C10. Precision Alpha-Alpha Scattering at Low Energies, II. G. M. TEMMER, *National Bureau of Standards*, AND N. P. HEYDENBURG, *Department of Terrestrial Magnetism.*—As stated in our last report, we have extended the investigation of the elastic scattering of Van de Graaf alpha-particles by helium both to the very low energy region and to energies up to 3 Mev. At the very low energy end we have looked with some care for the effect of the 180 degree phase shift in the s-wave scattering which must occur at the location of the virtual ground state of Be^8 (which we have shown to have $J=0$) which at that time was reported to be at 77.5±4 Kev (i.e., 155±8 kev lab). We have covered the range of laboratory energies corresponding to the range of 74 to 91 kev excitation in small voltage steps. The absence of any effect would permit us to set an upper limit on the level width (~7 ev) and hence a lower limit on the lifetime of that state (~10^{-16} sec). However, it has since come to our attention that the level position

quoted above was due to a spurious effect and that it is probably closer to 96 kev. We shall extend our search with our low energy electrostatic generator to cover this energy region in the near future. At the higher energies we have investigated the D-wave contribution to the scattering and were forced to measure absolute differential cross sections.

C11. Scattering of High Energy Electrons by Nuclei, I. E. C. RAKA, C. L. HAMMER, AND R. W. PIDD, *University of Michigan.*—Differential cross sections for the scattering of high energy electrons by nuclei have been measured using the internal beam of the University of Michigan synchrotron. The circulating beam is scattered by a target which is placed in one of the straight sections of the race track type of orbit. The target is a thin vertical wire at a radius corresponding to the inner edge of the synchrotron guide field. Beam energies are obtained in a continuous range up to 100 Mev by turning off the rf at any time in the accelerating cycle. The scattered electron beam emerges from the synchrotron vacuum system through 5-mil aluminum windows into the external detecting system. A one-ton lead collimator, a magnetic analyser, and a Geiger counter telescope serve as the scattered beam detector, and the system rotates as a unit through angles between 45 and 135 degrees with respect to the incident beam direction. A similar collimator, magnetic analyser, and counter telescope assembly is fixed at 90 degrees on the opposite side of the beam and serves as an intensity monitor. The background near the synchrotron has been reduced by the use of lead and Lucite shielding. A typical ratio of scattered electron counts to background is 20:1 at 30 Mev and at an angle of 90 degrees with respect to the incident beam.

C12. Scattering of High Energy Electrons by Nuclei, II. C. L. HAMMER, E. C. RAKA, AND R. W. PIDD, *University of Michigan.*—Differential cross sections for the scattering of high energy electrons on nuclei depart from the Mott formula based on a point Coulomb nucleus. In the range of incident electron energies being studied (20 to 100 Mev) the de Broglie wavelength of the electron is comparable with the nuclear size. Elastic scattering experiments at these energies are therefore expected to give information about the nature of the nuclear proton distribution. Previous work[1] has shown the departure from point scattering at 15.7 Mev. Data obtained on the Michigan synchrotron at 20 Mev are in good agreement with 15.7 Mev result. The cross section as a function of angle can be measured accurately on a relative scale by comparing the counts in the variable-angle detector with the fixed detector. It is not yet possible, however, to measure the absolute cross section, since neither the incident beam intensity nor the effective target thickness is known.

[1] Lyman, Hanson, and Scott, Phys. Rev. **84**, 626 (1951).

C13. Scattering of Electrons by Hydrogen Atoms.* HOWARD BOYET AND SIDNEY BOROWITZ, *New York University.*—The cross section for the collision of electrons with hydrogen atoms has been calculated in the range 0–10 volts using the Schwinger variational method for this problem.[1] The effects of exchange have not been considered here. Total cross sections can be calculated using the relation Q equals $4\pi/k$ times the imaginary part of the scattering amplitude in the forward direction. With a Born trial field the effect of virtual transitions to higher states, including the continuum, can be taken into account accurately. This procedure has also been applied to the calculation of the elastic scattering from the static field of the hydrogen atom. Comparison of the latter with exact cross sections obtained from phase-shift analysis[2] shows a striking improvement over the ordinary Born approximation at these low energies.

* Supported in part by contract with Geophys. Research Dir. A.F. Cambridge Res. Center, A.R.D.C.
[1] S. Borowitz and B. Friedman, Phys. Rev. (to be published).
[2] Chandrasekhar and Breen, Astrophys. J. **103**, 41 (1946).

C14. Deflection of High Energy Electrons in Magnetized Iron.* STEPHEN BERKO AND FRANK L. HEREFORD, *University of Virginia.*—Deflection experiments in magnetized iron show the macroscopic B to be the effective magnetic vector acting on μ-mesons. An experiment by Alvarez[1] in 1934 indicates, however, negative results for radium C β-rays. In a recent paper[2] Wannier showed that the magnetic deflection is separable from multiple scattering only at higher electron energies. The experiment to be described uses magnetically analyzed 7.4-Mev electrons from the $B^{11}(d, p)B^{12}(\beta^-)C^{12}$ reaction. The collimated electron beam is scattered by an iron (Vanadium Permendur) sheet and is detected by a movable counter telescope. Multiple-scattering curves are taken with the magnetic field in the iron in both directions. From the shift of the scattering distributions, the effective magnetic field is computed and found to be the macroscopic flux intensity B, showing therefore no short-range electron-electron forces at these energies.[2] Saturation effects will be discussed.

* Supported by the OOR, U. S. Army.
[1] L. Alvarez, Phys. Rev. **75**, 225 (1934).
[2] G. Wannier, Phys. Rev. **72**, 304 (1947).

THURSDAY MORNING AT 10:00

Geology Lecture Room

(J. STEINBERGER presiding)

Pi-Mesons

D1. Photoproduction of Positive π-Mesons on Hydrogen.* G. S. JANES AND W. L. KRAUSHAAR, *M.I.T.*—The cross section at 90° in the laboratory system for π^+ meson production is being measured using x-rays from the M.I.T. synchrotron and a polyethylene, carbon subtraction technique. We are particularly interested in the low energy ($5\ \text{Mev} < E_\pi < 20$ Mev) region, although we are also measuring the higher energy region. Our apparatus detects π^+ mesons in a single stilbine crystal by their characteristic $\pi-\mu$ decay. The resulting photomultiplier pulses are amplified, and a delayed coincidence arrangement triggers on a $\pi-\mu$ decay. Both pulses are displayed on a fast oscilloscope and photographed. The μ-pulse heights are all very nearly the same and correspond to the characteristic 4.15-Mev kinetic energy. For the low energy region we use thin targets and no absorber in front of our counter. The π^+ pulse height is thus practically a direct measure of the initial meson energy. Preliminary results indicate that the cross section as a function of meson energy for γ-rays on hydrogen probably starts from zero meson energy with some negative curvature.

* Supported in part by the joint program of the ONR and AEC.

D2. Photomesons from Hydrogen.* R. M. LITTAUER, A. M. PERRY, AND W. M. WOODWARD, *Cornell University.*—Hydrogen in a low temperature, high pressure target is bombarded with 310-Mev bremsstrahlung from the Cornell electron synchrotron. Charged mesons emitted at a given angle are detected in a coincidence-anticoincidence telescope which defines their ranges and identifies them by their specific ionization. In this way one obtains the excitation function for the process $\gamma+p\rightarrow n+\pi^+$ and the angular distribution of the emitted mesons. Preliminary results are in good agreement with the data of Steinberger and Bishop.[1]

* Supported by joint program of the ONR and AEC.
[1] J. Steinberger and A. S. Bishop, Phys. Rev. **86**, 171 (1952).

D3. The Analysis of Photomeson Production Data.* B. T. FELD, *M.I.T.*—The experimental evidence on the photoproduction of neutral and positive π-mesons from hydrogen can be analyzed on the assumption of intermediate states of definite angular momenta and parities. Thus, π^0 production can be described as resulting from the absorption of a magnetic dipole γ-ray into a $3/2^+$ intermediate state, with the consequent emission of a p-wave meson. This leads to the observed $2+3\sin^2\theta$ meson angular distribution and the proportionality near threshold of the cross section to the cube of the meson c. m. momentum. The π^+ production data require, in addition, absorption of electric dipole radiation to a $\frac{1}{2}^-$ state (emitted π^+ meson in an s state). The angular distribution should exhibit interference between the two processes. The absence of the electric dipole term from π^0 production can be accounted for by destructive interference between the isotopic spin $\frac{3}{2}$ and $\frac{1}{2}$ components. These considerations can be extended to take into account a possible resonant (isobar) interaction, to derive connections between meson scattering and photoproduction, and to predict the properties of elastic (Compton) photon scattering. This is an alternative formulation of the phenomenological theory of Brueckner and Watson.[1]

* The work described was supported in part by the joint program of the ONR and AEC.
[1] K. A. Brueckner and K. M. Watson, Phys. Rev. **86**, 923 (1952).

D4. $\pi^\pm$ Meson Production Cross Sections from Carbon by 341-Mev Protons. WALTER F. DUDZIAK, *University of California, Berkeley.*—Measurements have been made of the absolute $\pi^\pm$ meson production cross sections from carbon in the forward direction to a 341-Mev proton beam. The created mesons were magnetically separated and detected in Ilford C-2 (200μ) emulsions. The π^- spectrum is based on 605 star-forming π^- mesons. The star-prong distribution of these π^- mesons is in very good agreement with previously reported data. Within experimental error the integrated π^- cross section over meson energies, which is approximately $(7.1\pm.7)\times10^{-29}$ cm^2/ster, is the same as that observed at 90° to the proton beam. However, the following results are reported:

T_π (Mev)	56	72	110	130	160
π^-/π^+	0.063	0.054	0.02	0.002	0.000

The π^-/π^+ ratios in the forward direction vary markedly from that observed at 90° to the proton beam. As previously reported this large increase in high energy π^+ meson production may be the result of a resonance reaction which accompanies deuteron formation. As noted by the ratios the high energy cutoff of the π^- spectrum occurs much earlier than that of the π^+ spectrum. This separation is >25 Mev. Furthermore, the peak of the π^- spectrum is shifted toward lower meson energies ($T_{\pi^-}\sim72$ Mev) as compared with the peak of the π^+ spectrum ($T_{\pi^+}\sim100$ Mev).

D5. Low Energy π^+ Interactions in Beryllium.† F. TENNEY AND J. TINLOT, *University of Rochester.*—We have operated a pulsed magnet cloud chamber in the magnetically analyzed π^+ beam of the Rochester cyclotron. The chamber contained a $\frac{1}{4}$-inch beryllium plate. The experiment was performed at three different ranges of meson energy: 15 to 30, 25 to 38, and 35 to 50 Mev. The μ-meson and electron contaminations were believed negligible. Totaling the results from the three energy bands, we have found in a partial survey a total of 95 events in about 12,000 g-cm^{-2} traversed; this corresponds to a mean total cross section of 121 mb. The proportions of stars, stops, and scatters are about 6:3:2. There is no indication that the cross sections depend on the meson energy. Of a total of 16 scatterings greater than 30°, 12 were greater than 90°, and 8 were greater than 135°. This suggests a backward maximum.

† This project was supported by the AEC.

D6. Nuclear Cross Sections of Negative and Positive Pions.† M. W. AARONS, J. ASHKIN, F. FEINER,* J. G. GORMAN, L. SMITH,‡ *Carnegie Institute of Technology.*—Total cross sections for absorption and inelastic scattering for π^+ and π^- mesons on various elements have been measured as a function of energy. The mesons are produced by the Carnegie Tech synchrocyclotron and are observed in a manner similar to the one employed at Chicago[1] and Columbia.[2] The experiment was performed with a meson intensity of approximately 20 π mesons per cm^2-sec passing through the two defining counters separated by 1 meter. The π^+ intensity at 110 Mev is about 5 percent of the π^- intensity. Data on C, Al, Cu, and Pb at 110 and 150 Mev indicate that within our error (±15 percent) the cross sections are equal to the nuclear area. The π^+ cross sections are lower than the π^- cross sections, as would be expected from consideration of Coulomb effects[3].

† Supported in part by the AEC.
* National Science Foundation Predoctoral Fellow.
‡ Now at Radiation Laboratory, University of California, Berkeley, California.
[1] R. L. Martin, Phys. Rev. **87**, 1052 (1952).
[2] Chedester, Isaacs, Sachs, and Steinberger, Phys. Rev. **82**, 958 (1951).
[3] Byfield, Kessler, and Lederman, Phys. Rev. **86**, 17 (1952).

D7. Radioactive Products of the Interaction of π^- with As^{75}.† A. TURKEVICH AND JAMES B. NIDAY,* *University of Chicago.*—The magnetically analyzed 122-Mev π^- beam of the University of Chicago synchrocyclotron has been slowed down and absorbed in H_3AsO_4. The radioactive nuclides Ge^{69}, Ge^{75}, Ga^{66}, Ga^{68}, Ga^{70}, Ga^{72}, and Cu^{64} and Cu^{67} have been isolated radiochemically after the irradiation. The production of the radioactivity is a maximum at the range of the mesons. The contribution due to secondary neutrons has been estimated from the small amount of radioactivity beyond the range of the mesons. For the $(\pi^-; p, xn)$ reaction on As^{75}, the most probably value of x appears to be 5.5 with a width at half-height of 3. Thus, in this case, at least 90 Mev goes into kinetic energy of the particles. The results are in agreement with the hypothesis that the primary interaction of the meson is with a small number of nucleons in the nucleus which have an appreciable probability of escaping before sharing all of their energy with the whole nucleus.

† This work was supported in part by the AEC.
* Now at the California Research and Development Company, Livermore, California.

D8. Interaction of Negative Pions with Mercury.* NATHAN SUGARMAN AND AGNES HABER, *University of Chicago.*—The study of the fission of mercury by negative pions reported earlier[1] has been extended. The branching yield for fission of 122-Mev pions brought to rest in mercury is about 1 percent. This branching yield is essentially the same for pions in the energy range 105 to 122 Mev and is in agreement with that expected from the interaction of the pions with two nucleons of a nucleus and the cross section for fission by nucleons. The distribution of the fission products indicates that the fission process occurring with these mesons is similar to that occurring with protons of about 150-Mev energy.[2] The thallium fraction, isolated from the pion-irradiated mercury, was shown to

contain 1.8-hr Tl^{198} and 7-hr Tl^{199}. The yield of (p, xn) reactions, calculated from the yield of Tl^{198}, is about 1 percent of the meson reactions and is consistent with the number and energy of protons known to be emitted in meson reactions.

* Supported in part by a grant from the AEC.
[1] N. Sugarman, Phys. Rev. **86**, 604 (1952).
[2] L. Jodra, unpublished work, University of Chicago.

D9. Interaction of π^- Mesons with I^{127}. LESTER WINSBERG,* *University of Chicago.*—The 122-Mev π^- beam from the synchrocyclotron was slowed down by a copper absorber with a thickness of 34 g/cm² and then absorbed by iodine. Radiochemical purification revealed the presence of Te isotopes of mass 127, 118, and <118 ($T_{\frac{1}{2}}=2.2h$); Sb, 126, 122, and 117; and Sn, 121, 117, and 123 (40*m*) or 111 (35*m*). The maximum in the mass-yield curve occurs for the emission of approximately 6–7 neutrons in the case of Te, 5.5 in the case of Sb (on the assumption that the shape of the curve is the same as that of the As isotopes produced by π^- on bromine[1]), and 9 for Sn. Comparison with the results on bromine[1] indicates no shift in the yield curve for emission of only neutrons but the emission of approximately 1.5 and 3 more neutrons when 1 and 2 protons, respectively, are emitted from I^{127} than for the similar case with bromine.

* On leave from the Weizmann Institute of Science, Rehovot, Israel.
[1] T. T. Sugihara, doctorate dissertation, The University of Chicago, June, 1952.

D10. Absorption of Negative Pions in Hydrogen.* C. P. SARGENT AND M. C. RINEHART, *Columbia University.*—A 17-inch diffusion cloud chamber in 7800 gauss was exposed to the 85-Mev π^- beam of the Nevis cyclotron. The pions were slowed in copper and entered the chamber, filled with hydrogen, at 15 atmospheres. There were on the average eight meson tracks per photograph. About one percent stop in the two-inch sensitive layer.

Approximately 20 percent of the stopped mesons produce a negative electron. On the basis of preliminary range-curvature measurements all of these events are consistent with mu-electron decays. The remaining 80 percent are consistent with stopped pions. Both calculation and the mu-electron events indicate an efficiency for detection of electrons associated with stoppings of about 95 percent. Electron pairs have been observed by Perkins in cosmic-ray stars and by Schein in π^- induced stars. Lindenfeld, Sachs, and Steinberger, using counter techniques, have detected electrons directly associated with pions stopped in liquid hydrogen. Our results to date are that no electron pairs have been observed in 173 pion captures. The photographs also show that absorption at rest successfully competes with the pi-mu decay process in hydrogen at 0.0015 g/cm³.

* This work was performed under the joint program of the AEC and ONR.

D11. Production of High Energy Photons in Pion Collisions.* J. KESSLER, H. BYFIELD, L. M. LEDERMAN, AND K. ROGERS, *Columbia University.*—Of the known elementary processes that pions undergo in hydrogen and deuterium, i.e., scattering, absorption, charge exchange scattering, and radiative capture, the latter two have not been observed to take place in nuclear matter. Consequently, a search was made for high energy photons associated with the disappearance of energetic negative pions in flight. A one-inch carbon plate in the Nevis 16-inch cloud chamber was bombarded with 125 Mev pions. Lead plates, $\frac{1}{8}$-inch thick, were placed in front of and behind the carbon scatterer to materialize photons. In 20 000 g/cm² of pion traversal through carbon, three events were recorded in which a single electron-positron pair was spatially correlated with a meson stopping in the carbon. If these events are interpreted as charge exchange scatterings, we obtain a cross section of 15 millibarns or ~5 percent of geometric for this process. Applying the same criteria to each of the lead plates, we obtain from four events a cross section of 6 percent of geometric for charge exchange scattering in Pb. The energies of the observed photons are 95, 135, 80, 35, 65, 49, and 150 Mev. We draw the conclusion from these data that pions do produce high energy photons by collision in nuclear matter, although the cross section is small and the mechanism for this production is not established.

* Supported by the joint program of the AEC and ONR.

D12. The Internal Pair Production of γ-rays of Mesonic Origin: Alternate Modes of π^0 Decay. J. STEINBERGER, A. SACHS, AND P. LINDENFELD, *Columbia University.*—The internal pair creation of the γ-rays in the processes, $\pi^0 \rightarrow \gamma+\gamma$, $\pi^- + P \rightarrow \gamma + N$, has been observed in an experimental arrangement in which the products of the capture of stopped negative pions in hydrogen were analyzed using counters. The experimental conversion coefficient is 0.0080 ± 0.0017 per photon. The theoretical prediction is rather independent of special mechanisms and even photon energy; it is 0.0063. In addition, we have obtained an upper limit on the fraction of neutral mesons which decay directly into a pair: $\pi^0 \rightarrow e^+ + e^-$. This limit is one in two thousand.

D13. Charge Exchange Scattering of 40-Mev π-Mesons in Hydrogen and Deuterium.* A. ROBERTS, W. SPRY, AND J. TINLOT, *University of Rochester.*—We have detected gamma-rays produced by 40-Mev π^+ and π^- mesons in deuterium, and by π^- mesons in hydrogen. The magnetically analyzed meson beam traversed a counter telescope, emerging with 45 Mev, traversed a target, and emerged with 36 Mev. The gamma-rays were detected by a fourfold telescope at 90° to the meson beam. They were identified by measuring the difference in counting rate with lead and carbon radiators. While gamma-gamma coincidences have not yet been looked for, we ascribe most of the observed radiation to the decay of π^0 mesons produced by charge exchange. The hydrogen and deuterium effects were measured by $CH_2 - C$ differences and $H_2O - D_2O$ differences, respectively. The precision of the results is limited primarily by uncertainties in calculating the efficiency of the gamma ray telescope, using Wilson's analysis.[1] Preliminary observations lead to cross sections of about 3–4 mb for H and somewhat less for D. The oxygen and carbon cross sections are smaller than the H cross section.

* This work was supported by the AEC.
[1] R. R. Wilson, Phys. Rev. **86**, 261 (1952).

D14. Positive Pion Scattering in Hydrogen.* GERSON GOLDHABER AND LEON LEDERMAN, *Columbia University.*—Interest in the strong energy dependence of the π^+ hydrogen scattering has stimulated a search for 150 to 200-Mev π^+ mesons inside the vacuum chamber of the Nevis cyclotron. A large mass of lead was used to define a 180° focused beam of mesons emitted at 0° to the target. Preliminary exposures of G-5 nuclear emulsions were successful in detecting a flux of 10^4 pions per cm² per sec in the interval 135–155 Mev. These plates are being scanned "along the track." Hydrogen scatterings are identified by energy momentum conservation. A check of the scanning efficiency is made by comparing all Coulomb scatterings found between 5° and 20° with the calculated distribution. The pion energy is determined by the path in the cyclotron field and by range of similarly selected protons in a tapered absorber. The final path length of mesons is obtained by multiplying the number of nuclear events (47) by the mean free path (28 cm) obtained[1] with a similar scanning technique in the external 140-Mev π^- beam. To date, seven hydrogen scattering events have been found, yielding a cross section of ~170 mb.

* This work was performed under the joint program of the AEC and the ONR.
[1] G. Goldhaber and S. Goldhaber (to be published).

D15. Pion Scattering and Absorption Cross Sections in Lead and Carbon.* L. LEDERMAN, H. BYFIELD, J. KESSLER, AND K. ROGERS, *Columbia University.*—Elastic scattering, inelastic scattering, and star production cross sections for 125 Mev negative pions in lead and carbon have been determined. The 16-inch Nevis cloud chamber in a magnetic field of 9000 gauss was used to observe the meson interactions in lead and carbon plates. Energy resolution was such that a loss of 30 Mev or more was required for a scattering event to be termed "inelastic." In addition, a large contribution of stoppings to the cross section obscures the true ratio of inelastic scattering to star formation. The results corresponding to 5000 incident meson tracks are given in Table I. Angular distributions will be presented and discussed.

TABLE I. Cross sections in millibarns.

	Elastic scattering >20°	Elastic scattering >60°	Absorption and inelastic scattering
Carbon	185±26	96±15	320±41
Lead	840±126	430±64	2050±250

* This work was performed under the joint program of the AEC and ONR.

D16. Elastic Pion—Deuteron Scattering.* S. GOLDHABER, E. ARASE, AND GERSON GOLDHABER, *Columbia University.*—The elastic scattering of π^-+D was observed in D_2O loaded photographic emulsions. Ilford *G5* emulsions were exposed to the 140±5 Mev external π^- beam of the Nevis synchrocyclotron. π^-+D elastic scattering is uniquely identified when the recoil deuteron ends in the emulsion. Further tests are required to distinguish between π^-+D elastic, π^-+D inelastic, and π^-+P elastic scatterings, when the recoil prong leaves the emulsion. The scanning "by area" of the emulsions is in progress. The following results have been obtained. *D_2O loaded emulsions:* total number of pion interactions, 396; pion path in deuterium, 1550±150 g/cm²; pion path in hydrogen, 850±100 g/cm². Nine events were identified as π^-+D elastic scattering, while three other events with the recoil prong not ending in the emulsion could be due to one of the alternative scattering processes. This corresponds to σ (π^-D elastic)≃23 −30 mb. Eight of the elastic π^-+D scatterings are in the forward direction. *Nonloaded emulsions:* total number of pion interactions, 440; pion path in hydrogen, 950±100 g/cm². Four events were identified as π^-+P elastic scattering which corresponds to σ (π^-+P elastic)≃8 mb.

* This work was performed under the joint program of the AEC and ONR.

THURSDAY MORNING AT 10:00

Allston Burr, A

(P. LECORBEILLER presiding)

General Physics

E1. Remarks on the Theory of Condensation. A. J. F. SIEGERT, *Physics Department, Northwestern University.*—We have investigated the consequences of the hypothesis that a system of n interacting particles has a partition function q similar to that of the van der Waals gas, i.e., that there exists at certain temperatures a finite interval of values of the volume v for which $\partial^2 lgq/\partial v^2$ is positive, if n is a large number but small compared to Avogadro's number. If such a system is subjected to a certain force per unit area condensation occurs if the force per unit area is independent of the volume. The proof proceeds directly from the canonical ensemble and does not require the assumptions made in the conventional reinterpretation of the van der Waals curve, but it depends on the type of force assumed above. If a substance consists of m such systems and if interaction between the particles belonging to different systems is neglected, except for the requirement that the total volume of the substance is the sum of the volumes of the m systems, the isotherm of the substance can be shown to approach, in the limit of infinite m, three analytic parts, with the center part horizontal.

E2. The Thermal Diffusion Constant of HCl. A. Z. KRANZ AND W. W. WATSON, *Yale University.**—The thermal diffusion constant α of HCl has been measured using a two-bulb apparatus. The values obtained are $\alpha=+0.012$ for $T_r=685°$K, and $\alpha=-0.009$ for $T_r=229°$K. Similar data for other gases show α to vary linearly with T_r. Plotting the data this way, one finds the inversion temperature to be 360°K, or 1.11 times the critical temperature 324°K. The Lennard-Jones 9,5 model predicts the inversion temperature to be 1.54 times the critical temperature. Comparison is made with various molecular models. It is well known that it is difficult to make relative abundance measurements of HCl in a mass spectrometer due to noxious memory effects. A method of minimizing these effects is discussed. A 7-meter hot-wire thermal diffusion column has been used to find the values of pressure and temperature which will give the maximum separation. Some performance data are presented.

* Assisted by the AEC.

E3. The Molar Refraction of CO_2 as a Function of Density and the Age of the Gas. CLARENCE E. BENNETT AND VICTOR H. COFFIN, *University of Maine.*—Earlier measurements of the molar refraction of CO_2 by displacement interferometry indicated an unmistakable but unexplained negative dependence upon density in the 0 to 0.06 grams/cm³ range.[1] Later measurements, however, on gas from a new tank indicated no such density dependence, but a few very carefully controlled runs made considerably later produced the old curve with negative slope. A systematic series of measurements on samples from new tanks and from tanks which have stood for months to a year or two confirm the conclusion without exception that the graph of molar refraction *versus* density is a slopeless straight line for a fresh sample of CO_2, but a curve of negative slope and positive curvature for those samples which have aged. A chemical analysis, involving the passage of CO_2 over hot CuO, indicates a slight but measurable decrease in the weight of the CuO, thus confirming the suggestion that CO_2 under pressure reacts with the iron tank to produce a slight amount of CO. Such an impurity is detectable by interferometric measurements.

[1] Clarence E. Bennett and Victor H. Coffin, Phys. Rev. **83**, 193 (1951).

E4. The Scattering of Fast Nitrogen Molecules by Nitrogen. I. AMDUR AND W. T. LINDSAY, JR., *M.I.T.*—Results are reported for the total cross section for elastic scattering of 500- to 1500-ev nitrogen molecules by nitrogen gas. The apparatus for producing and detecting beams of molecules is described briefly, and a revised arrangement of the scattering section,

which allows analytical treatment of the beam as being of cylindrical shape with a finite radius, is explained. The results are interpreted in terms of the repulsive intermolecular potential-energy function $U(r)=317/r^{6.5}$ ev (r in A), valid in the region between $r=1.87$ $A[U(r)=10.1$ ev] and $r=2.27$ $A[U(r)=3.5$ ev]. This result indicates that the molecules are somewhat more yielding in high velocity collisions than would be predicted by the Lennard-Jones potential-energy function when using parameters determined by second-virial-coefficient measurements.

E5. Solid Angle Corrections for Light Scattering Measurements.* W. J. PANGONIS AND W. HELLER, *Wayne University.*—Light scattering measurements said to be made under an angle γ, e.g., 90° involve always the recording of an effect defined by a cone which at its apex presents an angle 2ω, where ω is the angle between the point intensity vector scattered at γ and the lateral surface of the cone. For the purpose of molecular weight and particle size determination a normalization factor K can be obtained by one of several methods. The common procedure is to consider this factor as constant. This is true, however, only for symmetrical radiation diagrams in the absence of depolarization. A systematic series of correction factors of K were therefore compiled for various α, m, and ω values, using as a basis the Mie equations. Defining by f the size dependent ratio of intensity of the scattered cone to that of the cone obtained in Rayleigh scattering, very substantial corrections are obtained. Taking as an example $\alpha=1.00$ (diameter = 130 mμ for $\lambda_0=546.1$ mμ), $f=0.5378$ equivalent to an error in particle size of 14 percent. The error in depolarization measurements is much larger than the corresponding error in simple intensity measurements. The error in turbidity measurements is much smaller since the intensity of the scattered cone is less than 2 percent of the total scattered intensity.

* This work was carried on under ONR Contract.

E6. Refractive Index Corrections for Molecular Weight Determined from Light Scattering.* W. HELLER AND W. J. PANGONIS, *Wayne University.*—Molecular weights can be obtained from light scattering measurements by means of the well-known Debye equation or the less practical Rayleigh equation as long as the radiation diagram is symmetrical. The results are almost identical if the ratio m of the refractive indexes of solute and solvent are sufficiently close to 1.0. This limiting ratio being an inherent restriction to the Debye equation, molecular weights obtained with it should be corrected for larger m values. A simple correction factor $F_m=M_r/M_d$ is found for the case of volume additivity of solvent and solute so that the modified Debye equation is $H\cdot c\cdot Fn/\tau=M$ at infinite dilution. Considering $m=1.20$ and the density of solute = 1.00 the correction factor is 1.0867. The value of F_m increases with molecular weight in the range of dissymmetrical scattering. In order to apply the practical Debye equation even in this range for which it is not intended, $F_m(M)$ functions were derived which become operative above an M of 5 000 000. Taking $m=1.20$ and an apparent M of 5 000 000 the upward revision amounts to about 1.5 percent.

* This work was carried on under ONR Contract.

E7. Observations of the Zodiacal Light During Total Solar Eclipse of February 25, 1952.* W. B. PIETENPOL AND W. A. RENSE, *University of Colorado.*—Photographs of the skylight in the vicinity of the eclipsed sun were taken from a B-29 during the total eclipse of February 25, 1952, at a point in the shadow path near the Red Sea in Saudi Arabia at an altitude of 32 000 feet. The photographs were taken through a plastic dome with a Schmidt-type camera of aperature $f/0.9$. A photometric analysis of the negatives yielded information about the intensity and degree of polarization of the light of the zodiacal glow between five and fifteen degrees from the sun. In reducing the data, the observed skylight was corrected for light arising from scattering in the earth's own atmosphere. The results indicate a brightness for the zodiacal light of about 0.15 ergs/cm²/sec/steradian at 5.5° from the sun and a polarization of about nine percent.

* This research was supported by the Air Force Cambridge Research Center Geophysics Division Contract.

E8. Origin of the Zodiacal Light.* J. M. JACKSON AND W. A. RENSE, *University of Colorado.*—Eclipse observations of the magnitudes and variations with solar elongation of the intensity and polarization of the zodiacal light in the region 5.5° to 13° of the sun are found to be consistent with the planetary theory of the origin of the zodiacal light. The data confirm predictions of intensity and polarization made on the basis of laboratory results of the study of light diffusely reflected from meteoritic particles.[1,2] The general character of the cloud causing the zodiacal glow may be as follows. Large and small meteoric particles extend from about 0.1 astronomical unit from the sun to outer parts of the solar system. Particle density in space varies inversely with distance from the sun. Closer to the sun the particles evaporate and a molecular (becoming finally mostly an electron and ion) cloud predominates. The F-component of the corona is continuous with this cloud.

* This research was supported by the Air Force Cambridge Research Center Geophysics Division Contract.

[1] F. Kloverstrom and W. A. Rense, Astrophys. J. **115**, 495 (1952).

[2] Wm. A. Rense, Astrophys. J. **115**, 501 (1952).

E9. A Bi-directional Electronic Counter for Use in Optical Interferometry. FRANKLIN H. BRANIN, JR., *Los Alamos Scientific Laboratory.*—A bi-directional electronic counter has been developed for both additive and subtractive counting of electrical impulses in either binary or decimal notation. Using two coherent syncopated sine wave input signals, such as may be derived from a Twyman interferometer with a stepped mirror and two phototubes, direction-sensing is obtained by pulse forming and selecting circuits which feed pulses to either the "add" or "subtract" channel, depending on the phase relation between the two input signals. In the binary counting circuit, the "add" and "subtract" channels each operate separate coincidence amplifiers which select the proper phase for transferring the trigger pulses from one binary stage to the next. In the decimal counting circuit, which consists of a binary stage followed by a reversible ring-of-five, additional coincidence amplifiers determine the direction in which the trigger pulses are transferred around the ring. Counting rates in excess of 200 kc have been achieved, and higher rates are possible with proper design. Although this circuit was developed primarily for the purpose of eliminating the tedium of visually counting interference fringes, it can also be used for differential counting with two separate (incoherent) pulse inputs.

* This work was done under the auspices of the AEC.

E10. A Single Crystal High Temperature Heater for an X-Ray Spectrometer. R. LEFKER, A. DEBRETTEVILLE, JR., AND J. S. DODD, *Squier Signal Laboratory.*—An oven was built on the end of a goniometer head for an x-ray spectrometer[1] for absolute intensity measurements. The temperature range is from 50° to 270°C and the temperature stability range is within ±0.1°C. The oven is less than 2 inches in diameter and 1¼ inches long, and is housed in a "Pyrex" Dewar. Two heater windings are provided of No. 40 wire, the main one of 300 and the auxiliary of 550 ohms radiate heat to a copper block in which the crystal is mounted. The main winding is continuously supplied with dc voltage (maximum 80 volts for 270°C). The auxiliary winding is controlled by an iron-constantan thermocouple in the copper block containing the

crystal. A Leeds and Northrup dc microvolt amplifier No. 9835-A, feeds voltage to a 6-mv Brown strip chart recorder with 1-second time constant, which is balanced at the midpoint. A microswitch on the pen drive servo mechanism turns the auxiliary heater on and off. A rough check was made of the crystal *vs* thermocouple temperature by using the 120°C or Curie point, tetragonal to cubic phase change of $BaTiO_3$, by means of x-ray diffraction.

[1] M. L. Barron and A. deBretteville, Jr., Rev. Sci. Instr. **21**, 458–461 (1948).

E11. The Propagation of a "Plastic" Wave in a Material Exhibiting a Strain-Rate Effect.* ROBERT J. RUBIN, *Applied Physics Laboratory, The Johns Hopkins University.*—We consider the propagation of stresses above the yield stress in a system consisting of a semi-infinite rod, of a material exhibiting a strain-rate effect. The rod is acted upon by a constant force suddenly applied to its free end. The static stress-strain curve is assumed to consist of two straight line segments whose slopes are E_{s1} and E_{p1}. The starting equations of this calculation are similar to those of Sokolovsky and Malvern.[1] We use the method of saddle points to calculate the distribution of strain for large times. The result is that for $\omega = x/at$ = constant and t large (a = sound velocity), the plastic strain has three different forms depending on the relative magnitudes of ω and $\gamma^{\frac{1}{2}} = (E_{p1}/E_{s1})^{\frac{1}{2}}$. There is a region $1 > \omega > \gamma^{\frac{1}{2}}$ of very small plastic strain followed successively by a transition region $\omega \approx \gamma^{\frac{1}{2}}$ and a region $\gamma^{\frac{1}{2}} > \omega > 0$ of relatively large plastic strain. The wave front of the region of small strains travels with the velocity of sound, *viz.*, $(E_{s1}/\rho)^{\frac{1}{2}}$. The transition region which is the "plastic" wave front propagates with the velocity of plastic wave propagation assumed by von Karman in a theory which neglects strain-rate effects, *viz.*, $(E_{p1}/\rho)^{\frac{1}{2}}$.

* This work supported by the Bureau of Ordnance, U. S. Navy.
[1] V. V. Sokolovsky, Prikladnaia Matematika i Mekhanika **12**, 261 (1948); L. E. Malvern, J. Appl. Mech. **18**, 203 (1951).

E12. Fade-Time of Rayleigh Distributed Random Function. L. M. SPETNER, *Johns Hopkins University.*—In many radar applications it is important to know something about the fade-time of a radar signal. If it is assumed that the signal is Rayleigh distributed, an expression can be derived for the expected length of time between the instant the signal drops below an arbitrary threshold level until it next rises above it. This expected time turns out to be $\psi_0/z(\pi/-\psi_0'')^{\frac{1}{2}}[\exp(z^2/\psi_0)-1]$, where z is the threshold level, ψ_0 and ψ_0'' are, respectively, the auto-correlation functions of the random signal and its second derivative both evaluated at zero. The derivation will be indicated.

E13. Low Frequency Oscillator, Circular Sweep Generator, and Direct Reading Phase Measuring Instrument. S. LEES, W. D. GREEN, AND E. T. COLTON, *M.I.T.*—A low frequency oscillator has been assembled using conventional analog computer components combined to form an undamped second-order system. Frequency range is 0.01 to 100 cps. Lower frequencies are available by adding external capacitors. Output is $\sin\omega t$ and $\cos\omega t$ of equal amplitude, constant at all frequencies, giving x and y circular sweep components for a cathode-ray oscilloscope as well as sinusoidal signal for testing equipment. Amplitude stabilization is provided by nonlinear combination of small amounts of positive and negative damping. Reference axes are displayed at the control of the operator. Phase angle is indicated on circular sweep by z axis signal when measured output from equipment crosses zero reference position. Application is illustrated with a galvanometer and photoelectric pick-off. Phase angle can be measured to within ± 3 degrees.

E14. Ross Filter Design for X-Ray Scattering Experiments.* W. L. GORDON† AND J. A. SOULES,‡ *Department of Physics, Ohio State University.*—Continuous and line radiations from Machlett copper and cobalt diffraction x-ray tubes have been determined between 0.3 and 2 *A* with a single crystal spectrometer using *G M* counter registration. Experimental results are compared with the Kulenkampff equation[1] after suitable correction for crystal reflection, air absorption, counter efficiency and a thin film of target material evaporated onto the inside of the x-ray tube window. The use of this distribution in the calculation of the optimum Ross filter is discussed.

Error in determining the differential intensity in low intensity scattered radiation arises mainly from two sources: statistical effects and mismatch of the filters. It is shown that the latter error may be made negligible when a strong characteristic line lies in the window. The effect of counter background on the former error is pointed out, when scattered intensity is very low. The use of a permanent filter is discussed.

* Supported by a Research Corporation grant.
† General Electric Company Coffin Fellow.
‡ Du Pont Fellow.
[1] Kulenkampff, Ann. Phys. **69**, 548 (1922).

THURSDAY MORNING AT 10:00

Jefferson 250

(H. A. BOORSE presiding)

Cryogenics

EA1. Statistical Basis of Two-Fluid Models of Superconductivity. PAUL M. MARCUS, *Carnegie Institute of Technology.*—In view of recent support for two-fluid models of superconductivity, a statistical basis for these models is desirable which eliminates the phenomenological description in terms of a condensed superconducting electronic phase and a remaining fraction of normal electrons. The model can be related to the usual band picture of electrons in metals moving individually in the mean periodic potential of all other electrons and the lattice, provided we assume electrons can condense, presumably combining with lattice vibrations, and alter the mean potential in which all the electrons move. This process plausibly alters the energy-wave number relation for any single electron in two ways, by depressing the energy levels near the Fermi level, and by decreasing the density of states at the Fermi level. These two aspects of the change in the distribution of all the electrons correspond to the two phases of the two-fluid model, the former yielding a condensation energy proportional to the degree of condensation ω, and the latter an entropy decrease also depending on ω. Condensation is then favored at a sufficiently low temperature and results from a cooperative interaction expressed by alteration of the mean potential, thus resembling the collective electron picture of the ferromagnetic condensation.

EA2. Some Aspects of the Two-Fluid Model of Superconductivity.* E. MAXWELL, *National Bureau of Standards,* AND P. M. MARCUS, *Carnegie Institute of Technology.*—The

two-fluid model of a superconductor has derived added support from the recent observation that the threshold curves for a family of superconducting isotopes are geometrically similar curves, a fact consistent with the model.[1] This is true for any two-fluid model in which the normal fluid alone contributes entropy. The detailed shape of the threshold field curve is determined by the particular form chosen for the entropy (or for the free energy) of the superconducting state. One specific form (α-model) was proposed by Gorter and Casimir[2] on heuristic grounds, another by Koppe.[3] Precise measurements on Sn, Hg, Tl, and In support the critical field equations calculated from the α-model:

$$\left(\frac{H}{H_0}\right)^2 = 1 - \frac{1}{\alpha}\left(\frac{T}{T_c}\right)^2 + \frac{1-\alpha}{\alpha}\left(\frac{T}{T_c}\right)^{2/(1-\alpha)},$$

where α is a parameter characteristic of each superconductor.

* Supported in part by the Office of Scientific Research, Air Research and Development Command.

[1] E. Maxwell, Phys. Rev. **87**, 1126 (1952).
[2] Gorter and Casimir, Physik. Z. **35**, 963 (1934).
[3] H. Koppe, Ann. Physik **1**, 405 (1947).

EA3. Nuclear Alignment and the Entropy of Liquid He³. BERNARD M. ABRAHAM, DARRELL W. OSBORNE, AND BERNARD WEINSTOCK, *Argonne National Laboratory.*—Since the slope of the melting pressure of He³ as a function of temperature is positive over the range 0.5°K to 1.5°K, it is apparent from the Clapeyron equation that the entropy of liquid He³ is greater than that of the solid in this temperature range. Consequently, any calculations that imply an appreciable ordering of the nuclear spins in the liquid above 0.5°K are inconsistent with the accepted assumption that the nuclear spins are randomly oriented in the solid above about 0.01°K. It is concluded that down to at least 0.5°K the nuclear spins in liquid He³ are still randomly oriented and that the entropy contains the full contribution from the spins, *viz.*, $R \ln 2$.

The following expression for the entropy of liquid He³ (including the nuclear spin entropy) is consistent with the vapor pressure measurements and with the melting pressure measurements: $S_{\text{liq}} = R \ln 2 + 0.344RT + 0.013RT^3$.

EA4. Optical and Infrared Reflectivity of Metals at Low Temperatures. T. HOLSTEIN, *Westinghouse Research Laboratories.*—The theory of the anomalous skin effect[1] in metals at low temperatures may be simplified considerably for optical and near infrared frequencies. In this frequency domain, the distance, $2\pi v/\omega$, traversed by an electron during an electromagnetic cycle is generally small compared to the electron mean free path l and to the skin depth $\delta \simeq (mc^2/4\pi ne^2)^{\frac{1}{3}}$. As a first approximation one assumes the electromagnetic field to be that characteristic of a stationary but otherwise free electron gas. The anomalously high metallic absorptivity exhibited in reference 1 (Fig. 4) for the optical and near infrared region may then be explained straightforwardly in terms of an "electronic loading" effect involving a transfer of energy from the electromagnetic field to the electrons traversing the skin-depth region. For the case of diffuse reflection of electrons at the surface, the absorptivity $A_{\text{diff}} = (3/4)v_0/c$ (with v_0 the Fermi velocity), in order of magnitude agreement with experiment.[2] For the case of specular reflection, we obtain $A_{\text{spec}}/A_{\text{diff}} = (2/3)(v_0/\omega\delta)^2 \ll 1$. Our result for A_{spec} agrees with the graphical result of reference 1 (Figs. 3 and 4) under the conditions $(v_0/\omega\delta)^2 \ll 1$, and $l \gg \delta$.

[1] G. E. H. Reuter and E. H. Sondheimer, Proc. Roy. Soc. (London) **A195**, 336 (1948).
[2] K. G. Ramanathan, Proc. Phys. Soc. (London) **A65**, 532 (1952).

EA5. Second Sound Velocity in Mixtures of He³–He⁴.† J. C. KING AND HENRY A. FAIRBANK, *Yale University.*—A further study of the properties of second sound in He³–He⁴ mixtures[1] has been made using the pulse technique. The second sound velocity has been determined as a function of temperature down to 1.0°K and as a function of concentration up to 4.3 percent He³. In the region of 1°K the velocity continues to increase with increasing concentration, reaching a value of 37 m/sec in 4.3 percent He³. This is in reasonable agreement with preliminary measurements reported at the G. E. Cryogenics Conference by Weinstock and Pellam, using a thermal, Raleigh disk apparatus. The velocity goes to zero at the λ-point providing a good method of measuring the λ-point shift as a function of He³ concentration. An extension of these measurements to temperatures below 1°K is in progress.

† Assisted by the ONR.
[1] E. A. Lynton and H. A. Fairbank, Phys. Rev. **80**, 1043 (1950).

EA6. A Method of Measuring Specific Heats at Very Low Temperatures. E. MENDOZA, *Carnegie Institute of Technology* (introduced by J. E. Goldman).—Angstrom in 1861 measured the diffusivity (the ratio of thermal conductivity to specific heat) of metals by finding the velocity of propagation of temperature oscillations along a rod. The method can be adapted to temperatures in the helium range and below 1°K. Sinusoidal temperature variations are generated in a heater at the end of a rod, and two quickly responding carbon resistance thermometers (colloidal graphite films painted over thin insulating films on the metal) spaced down the rod undergo sinusoidal variations of resistance; the phase difference between them can be measured. Frequencies between 10 and 10^3 cps are being used. It is necessary to develop the analog with a transmission line. The thermal impedance of the calorimeter wall at the far end of the rod is usually equivalent almost to a short circuit, and large corrections are necessary at low frequencies. The same apparatus can be used to measure the thermal conductivity of the specimen, and hence, the specific heat can be measured. Since the diffusivity of metals is approximately independent of temperature at low temperatures, high accuracy of specific heat measurement is in principle possible at the lowest temperatures.

Post-Deadline Papers, if Any

THURSDAY MORNING AT 10:00

Sanders Theatre

(L. J. HAWORTH presiding)

New and Prospective Accelerators at Brookhaven

EB1. The Brookhaven Cosmotron, G. K. GREEN, *Brookhaven National Laboratory.* (45 min.)

EB2. The Alternating-Gradient Focusing Principle. H. S. SNYDER, *Brookhaven National Laboratory.* (30 min.)

EB3. Accelerators Incorporating Alternating-Gradient Focusing. J. P. BLEWETT, *M.I.T. and Brookhaven National Laboratory.* (30 min.)

THURSDAY AFTERNOON AT 2:00

Allston Burr, B

(E. M. PURCELL presiding)

Invited Papers

F1. Paramagnetic Resonance Resulting from Conduction-Electrons in Metals. A. F. KIP, *University of California, Berkeley.* (30 min.)

F2. Spin-Echo Pulse Technique in Nuclear Resonance Studies. E. L. HAHN, *Watson Laboratories.* (30 min.)

F3. Nuclear Quadrupole Resonance. H. G. DEHMELT, *University of Goettingen (temporarily at Duke University).* (30 min.)

Nuclear Quadrupole Resonance

F4. Nuclear Quadrupole Transistions in Paradibromobenzene. EDWARD MANRING, CARLTON BROWN, AND DUDLEY WILLIAMS, *The Ohio State University.**—Absorption peaks resulting from nuclear quadrupole transitions have been observed in *p*-dibromobenzene at room temperature. Superregenerative techniques were employed in a Zeeman-effect-modulated spectrograph. The absorption line due to Br^{81} occurs at 223.8±0.5 mc, and that due to Br^{79} appears at 267.6±0.5 mc. The quadrupole ratio Q^{79}/Q^{81} obtained from the present measurements is 1.196, a value in fair agreement with the ratio 1.197 based on microwave measurements.

* Supported in part by Contract between Flight Research Laboratory, Wright Air Development Center, and Ohio State University Research Foundation.

F5. Line Width in Pure Quadrupole Resonance Experiments in Crystals. K. KAMBE AND A. ABRAGAM, *Harvard University* (introduced by J. H. Van Vleck).—The mean-square width due to dipole-dipole interaction in zero magnetic field has been calculated for the case of like nuclei of spin one in an electric field of cylindrical symmetry, by extending Van Vleck's methods. Previous calculations by Stevens, Kambe, Ollom, and others, assume a nonvanishing magnetic field and do not apply to the zero field case which demands a special treatment. The result can be applied to other experiments in zero external field such as nuclear resonance in solid hydrogen or paramagnetic resonance in nickel fluosilicate. With the usual notations and neglecting exchange, one finds

$$h^2\langle\Delta\nu^2\rangle_{Av}=\tfrac{1}{4}\,\Sigma_j\, g^4\beta^4 r_{ij}^{-6}\{5(1-3\gamma_{ij}^2)^2+g(1-\gamma_{ij}^2)^2 -2(1-3\gamma_{ij}^2)(\alpha_{ij}^2-\beta_{ij}^2)\}.$$

A straightforward extension covers the case of "semilike" nuclei for which the gradient of the electric field has the same value but different directions.

F6. Nuclear Quadrupole Resonances in Some Bromine and Iodine Compounds. A. L. SCHAWLOW, *Bell Telephone Laboratories.*—Resonances in the 100–400 megacycle range due to Br^{79}, Br^{81}, and I^{127} have been observed in a number of solid halogen compounds, using a super-regenerative detector. The substances include *p*-dibromo and *p*-di-iodo benzene, cyanogen bromide, several bromates, and most of the tetrahalides of carbon, silicon, germanium, and tin. Temperature coefficients of resonance frequency are of the order of 10^{-4} per degree. The resonances in sodium bromate, near 150 and 180 mc, are exceptionally sharp, having an effective Q of the order of 10^5. In BrCN, the quadrupole coupling is higher than in the gas, which suggests intermolecular bonding. The tetrahalides show regularities in quadrupole coupling which can be correlated with chemical bond structures. The number of resonances and their spacing indicate that the tetrahalides include several groups of isomorphous compounds. Tin tetrabromide undergoes a transition from one to another of these groups below room temperature. I wish to thank C. E. Miller for the preparation of most of the compounds.

F7. Nuclear-Molecular Interactions of Li^7F^{19}.* R. BRAUNSTEIN AND J. W. TRISCHKA, *Syracuse University.*—Radio-frequency spectra of Li^7F^{19} were investigated by the electric resonance method of molecular beam spectroscopy. Data were taken on the $(J, m_j)\rightarrow(J, m_j')$ transitions $(1, 0)\rightarrow(1, \pm1)$ and $(2, 0)\rightarrow(2, \pm2)$ at both very weak and strong electric fields; i.e., fields in which the effects of the nuclear-molecular interactions are either much greater than or very much less than the Stark effect. The latter transitions were observed by the two quantum process first investigated by Hughes and Grabner[1]; whereas these transitions were observed by them at weak fields, the present observation is the first made at strong fields. Considerable simplification of the spectra and their subsequent analysis results from the use of the double quantum transitions in this instance. The quadrupole interaction of Li^7 was determined to have the same sign and magnitude as found by the magnetic resonance method.[2] The F spin-rotation interaction in Li^7F^{19}, when account is taken of the difference between the reduced masses of the two molecules, is consistent with the value found in Li^6F^{19}.[3]

* Supported in part by the ONR.
[1] V. Hughes and L. Grabner, Phys. Rev. **79**, 829 (1950).
[2] Logan, Cote, and Kusch, Phys. Rev. **86**, 280 (1952).
[3] J. C. Swartz and J. W. Trischka, Phys. Rev. **86**, 606 (1952).

F8. The Pure Quadrupole Spectra of HCl and DCl.* H. C. MEAL AND H. C. ALLEN, JR.,† *Harvard University.*—Using a frequency modulated super-regenerative spectrometer, the pure quadrupole spectra of HCl and DCl have been observed. At liquid nitrogen temperature, the frequencies for the two chlorine isotopes in HCl are 26.469 and 20.862 mc, while in DCl the corresponding frequencies are 27.310 and 21.523 mc. The ratio of the quadrupole moments of the two isotopes, Cl^{35}/Cl^{37}, found from these measurements is 1.2688 in agreement with previous determinations.[1] The unusually large width of these lines introduces some uncertainty in the positioning of the frequency markers; hence, small differences in this ratio between the two compounds could not be detected. Attempts were made to measure the absorption of HCl above the phase transition at about 89°K. No absorption was found, which lends support to the hypothesis that this is an order-disorder transition.[2] On the basis of Hornig's model, hydrogen bonding in the HCl crystal will be discussed.

* Supported by the ONR.
† AEC Postdoctoral Fellow.
[1] R. Livingston, Phys. Rev. **82**, 289 (1952).
[2] G. L. Hiebert and D. F. Hornig, J. Chem. Phys. **20**, 918 (1952).

F9. Nuclear Quadrupole Coupling in Solids. M. H. COHEN, *University of Chicago.**—Calculation of the nuclear quadrupole coupling in a solid entails calculation of the tensor components

of the local electric field gradient at the nucleus. An approximate method for such calculations is described. Contributions to the field gradient arise from charge density both internal and external to the atom, ion, molecule, or cell within which the nucleus lies. External contributions depend on the dipole field factors of the lattice and the fraction of the charge density associated with each lattice point which is spherically symmetric. The internal contribution in ionic crystals can be calculated by perturbation theory, but in metallic and covalent crystals a more detailed knowledge of the valence electron wave function proves necessary. A calculation of the local field gradient in metallic beryllium has been made to illustrate the features of the method. The result is compared with experiment.

* Performed in part at the University of California, while the author was an AEC predoctoral fellow.

THURSDAY AFTERNOON AT 2:00

Sanders Theatre

(W. W. HAVENS, JR., presiding)

Invited Papers

G1. Mesonium. JAMES RAINWATER, *Columbia University.* (30 min.)
G2. Photomeson Production from Hydrogen. L. S. OSBORNE, *M.I.T.* (30 min.)

Mesons, I

G3. μ-Meson Capture Probabilities for Intermediate *Z* Elements. A. J. MEYER AND J. W. KEUFFEL, *Princeton University.**—The measurements of μ-meson capture probabilities previously reported[1] are being extended by means of an apparatus which permits the use of smaller targets. The capture probability *vs Z* curve is found to level off in the fifty-proton region at a value near 10 μsec^{-1} before increasing to the values previously found for the Hg-Pb-Bi group. Capture probabilities for Cd, In, Sn, and Sb will be reported. With improved liquid scintillators and a more efficient geometrical arrangement, the rate of μ-meson capture from the sea-level cosmic radiation is now about 2 hr^{-1} for a 5 kg target. Targets of 50 to 100 kg had previously been required for the same rate. A lifetime measurement to 10 percent accuracy takes about 10 days. The statistical accuracy of the results is being improved and additional elements are being measured.

* Supported by the AEC and ONR.
[1] Keuffel, Harrison, Godfrey, and Reynolds, Phys. Rev. **87**, 942 (1952).

G4. Calculations on μ-Meson Capture in Nuclei. J. R. HUGH DEMPSTER, *Princeton University.**—The lifetimes for capture of negative μ-mesons in various elements have been calculated by a method similar to that of Kennedy.[1] A nuclear shell model is used, but with harmonic oscillator instead of square-well wave functions. This avoids the need for numerical integrations, thus permitting slight improvements in Kennedy's procedure and extension of the work to many other elements. Lifetimes in reasonable agreement with experiment are obtained with a coupling constant equal to that for β-decay. Because the energy level spacings obtained from this model of the nucleus are very much larger than those known experimentally, the results have been modified by arbitrarily introducing rough empirical energy levels. This tends to increase the capture rate by some 40 percent, but it makes possible an estimate of the neutron emission probability. For example, the absence of neutrons in calcium[2] may be understood. The neutron multiplicities to be expected in some other elements will be discussed.

* Supported by the joint program of the ONR and AEC.
[1] J. M. Kennedy, Phys. Rev. **87**, 953 (1952).
[2] A. M. Conforto and R. D. Sard, Phys. Rev. **86**, 465 (1952).

G5. Interactions of μ-Mesons.* WILLIAM D. WALKER,† *University of California, Berkeley.*—The energy spectrum of electrons knocked on by μ-mesons has been measured over a wide range of energies. It is found that the theoretical cross section as derived by Bhabha[1] fits the data over a range of knock-on energies, from a few Mev up to energies of the order of a Bev. From these data it is concluded that any particle structure that might exist produces no large effect for collisions with impact parameters of the order of 6×10^{-13} cm. It is found that the theoretical cross section for direct pair production by μ-mesons is of the right order of magnitude. From the experiment, an upper limit of 2×10^{-29} cm^2/nucleon is set for the cross section for the production of a penetrating secondary particle of the type originally reported by Braddick and Hensby.[2]

* Supported in part by the joint program of the ONR and AEC.
† Now at the Physics Department, University of Rochester, Rochester, New York.
[1] H. J. Bhabha, Proc. Roy. Soc. (London) **A164**, 257 (1938).
[2] H. J. J. Braddick and G. S. Hensby, Nature, 1012 (1939).

G6. Range Distribution of μ-Mesons from π-Meson Decays in Photographic Emulsions.* GEORGE R. WHITE AND W. F. FRY,† *Iowa State College.*—The lengths of μ-meson tracks from 1000 π-meson decays have been measured in two Ilford *C-2* 200 micron thick emulsions, which had been exposed by R. Sagane in a spiral orbit spectrometer to the Berkeley cyclotron. Shrinkage factors for each plate were determined by applying statistical regression techniques to correlate the ranges of tracks and their vertical projections. The shrinkage factors obtained from this analysis were used to calculate the true ranges of the μ-meson tracks. The distribution of true ranges meets statistical tests for a Gaussian distribution; It has a mean of 597 ± 1 microns and a standard deviation of 29.1 ± 0.7 microns. Since decay in flight and soft photon emission accompanying decay have negligible effects in this study, the straggling parameter for 4.1-Mev μ-mesons in photographic emulsions can be obtained; it is 4.86 ± 0.12 percent. The effect of experimental uncertainties on these values can be about 0.1 percent, which is slightly less than the statistical limits imposed by the finite number of events.

* Supported in part by a grant from the Research Corporation.
† Now at the University of Wisconsin, Madison, Wisconsin.

G7. A Photographic Study of the Muon Range Spectrum from π→μ Decay.* A. M. SEIFERT, H. J. BRAMSON, AND W. W. HAVENS, JR., *Columbia University.*—The search for anomalous μ-meson ranges and the compilation of the range

spectrum from $\pi \rightarrow \mu$ decay is being continued.[1] The experimental technique has been improved by using underdeveloped *B*-2 Ilford emulsions. A measurable change in grain density is now always obtained at the $\pi - \mu$ junction. To date, over 5000 μ-meson ranges have been measured yielding the expected modified Gaussian shape. However, 18 tracks were found which had ranges under 500 microns and 11 that were above 700 microns, which cannot be easily reconciled with theory.[2] Only nine of the mesons with short ranges can be due to decay in flight of the π-meson in the backward direction. These data are not inconsistent with the results of Fry.[3] Several tests were made on each plate to find possible sources of error due to physical distortion of the emulsion, as plate distortion can severely affect range measurements. Detailed results of these distortion tests and of increased statistics will be presented.

* This research is being assisted by the joint program of the ONR and AEC.

[1] Seifert, Bramson, and Havens, Phys. Rev. **86**, 603 (1952).
[2] H. W. Lewis, Phys. Rev. **85**, 20 (1952); Tetsuo Eguchi, Phys. Rev. **85**, 943 (1952).
[3] W. F. Fry, Phys. Rev. **87**, 219 (1952).

G8. Photoproduction of Neutral Mesons in Hydrogen. Y. GOLDSCHMIDT-CLERMONT, L. S. OSBORNE, AND M. B. SCOTT,* *M.I.T.*—The gamma-ray beam of the M.I.T. synchrotron operating at 320 Mev was passed along the axis of a cylindrical chamber containing hydrogen at 625 psi and -60°C. The recoil protons arising from the photoproduction of neutral mesons were detected in photographic emulsions placed inside the tank. From angle and range measurements the center-of-mass energy k of the incident photon and the angle θ and momentum p of the neutral meson were determined on 1080 individual events. The observed excitation curve is proportional to p^3k in the low energy region and the angular distribution is compatible with a $1+1.5\sin^2\theta$ shape. These results are consistent with the phenomenological theory of Brueckner and Watson. As reported by B. T. Feld in another abstract, they are explained by the assumption of an intermediate state of the nucleon with spin $\frac{3}{2}$ and even parity, and a magnetic dipole interaction of the gamma-ray.

* This work was supported in part by the joint program of the ONR and AEC.

THURSDAY AFTERNOON AT 2:00

Paine Hall

(HARVEY BROOKS presiding)

Solid-State Physics (*Nonmetals*)

H1. Plastic Deformation in Ammonium Dihydrogen Phosphate Crystals. E. I. SALKOVITZ AND P. L. SMITH, *Naval Research Laboratory.*—Plastic deformation was produced in ADP single crystals at about 100°C. ADP is normally considered to be a brittle material and shows brittle fracture characteristics at room temperature. No well-defined cleavage plane is found. Crystals in the form of bars $1\frac{1}{2}$ in. $\times \frac{1}{2}$ in. $\times \frac{1}{4}$ in. were loaded usually as a simply supported beam. A given deformation was applied, and the specimen was allowed to relax. Then additional deformation was applied. The crystals always bent about the loading axis. Crystals could also be bent by end-loading as a column. Four specimen orientations were studied: (a) loaded along [110] axis normal to the (001) face (this orientation being the one of practical importance for all piezoelectric applications), (b) loaded along [100] axis normal to (001) face; (c) loaded along [010] axis normal to (100) face; (d) loaded along [001] axis normal to (100) face. Specimen (a) deformed more readily than the others. X-ray studies were made before and after deformation. Back reflection Laue patterns revealed no difference before and after deformation (i.e., no asterism was detected). A modification of the Barrett-Berg grazing angle technique proved very satisfactory and revealed that structural fragmentation had occurred in these crystals.

H2. Structure of SiO_2 and B_2O_3 Glasses Compacted by Very High Pressures.* IVAN SIMON, *Arthur D. Little, Inc.*—It has been shown[1] that glasses exposed to hydrostatic or uniaxial pressures of the order of 50 to 100 kiloatmos may increase their densities by several percent (up to 17 percent in vitreous SiO_2). Compacted specimens of vitreous SiO_2 and B_2O_3 have been studied by x-ray diffraction using the conventional cylindrical camera techniques with filtered but nonmonochromatized Cu$K\alpha$ radiation. Examination of the diffraction halos of the compacted vitreous B_2O_3 indicates that the collapse of the glass structure takes place on the atomic scale, leaving, however, the nearest neighbor distance of B$-$O approximately unchanged. Broadening of the diffraction halos indicates increase of disorder in the glass network as a result of the rearrangement by compression. Similar effects are observed in vitreous silica. In case of samples compacted under nonhydrostatic (uniaxial) conditions, uniaxial anisotropy is observed. The collapse of the glass network under pressure is pictured as involving bond-bending rather than actual shortening of the Si$-$O and B$-$O distances.

* Research sponsored by the Owens Illinois Glass Company, Toledo, Ohio.
[1] P. W. Bridgman, Proc. Am. Acad. Arts Sci. **81**, 165 (1952).

H3. Space Charge Layer and Distribution of Lattice Defects at the Surface of Ionic Crystals. KURT LEHOVEC, *Sprague Electric Company.*— The thermal equilibrium concentration of lattice defects in an ionic crystal is calculated for the general case that an electrostatic potential exists between surface and an arbitrary position in the crystal. It is shown that the zero space charge condition for the bulk of the crystal requires the establishment of an electrostatic potential between bulk and surface, which can be expressed by the energies necessary to create the lattice defects. The distribution of space charge and of potential in the surface layer, and the change in ionic conductivity due to the surface space charge layer are calculated. The equations are applied to Frenkel defects and to Schottky defects. For Schottky-defects the potential between bulk and surface equals $1/2e$ of the difference between energies of formation of positive and negative ion vacancies, which is in case of NaCl -0.28 volts (using the energy values calculated by Mott and Littleton[1]). Some implications of the surface space charge layer in ionic crystals on the behavior of electrons and holes liberated in the crystals will be mentioned.

[1] N. F. Mott and N. J. Littleton, Trans. Faraday Soc. **34**, 485 (1938).

H4. Small Angle X-Ray Scattering in Deformed Crystals. S. HAYES, R. SMOLUCHOWSKI, AND R. W. TURNER, *Carnegie Institute of Technology.**—Small angle x-ray scattering is an indication of nonuniformity of distribution of electronic charge. Such nonuniformity may arise from introduction of defects

such as vacancies, dislocations, and cracks into a crystalline lattice. Disperse imperfections produce scattering at relatively large angles; clustering of imperfections increases scattering at smaller angles. The scattering of x-rays by a deformed and by a recrystallized copper sample has been measured down to an angle of ten minutes. At large angles, the scattering by the deformed sample tends to be greater than the scattering by the recrystallized sample. This is in accord with recent data obtained by Guinier. At small angles, however, the situation is reversed, and the scattering is greater for the recrystallized than for the deformed metal. A tentative interpretation of these results will be given.

* Work supported by an AEC Contract.

H5. The X-ray Path Through Calcite for Anomalous Transmission.* GUENTER SCHWARZ, L. CARLTON BROWN,† AND G. L. ROGOSA, *Florida State University.*—The transmission of x-rays through single crystals of calcite has been studied for the case of Laue diffraction. Previous work has shown that for each wavelength there exists a "thick" crystal case for which the transmitted intensity increases as the crystal is rotated through a diffracting position. The path of the radiation through the crystal has been determined using monochromatized Mo$K\alpha_1$ radiation. The cross sections of the ordinary and the anomalously transmitted x-ray beams have been measured, respectively, using a 0.06-mm wide slit and a high pressure Geiger-Mueller counter; the incident beam was 0.65 mm wide. The recorded curves show that the anomalously transmitted beam widens out on one side, thus confirming that the diffracted radiation is propagated through the crystal mainly along the reflecting planes and upon leaving the crystal splits up into a diffracted and transmitted beam. von Laue,[1] using the dynamical theory of x-ray diffraction, has recently discussed these phenomena.

* This work is supported by a grant from the National Science Foundation.
† Now at Ohio State University.
[1] M. von Laue, Acta Cryst. **5**, 619 (1952).

H6. Extend of Perfect Single Crystal Regions within Imperfect Single Crystals. G. L. ROGOSA AND GUENTER SCHWARZ, *Florida State University.**—Studies of the anomalous transmission of x-rays in the Laue diffraction case have been made mainly for perfect calcite and quartz crystals. The intensity of the transmitted beam has been shown to undergo large changes as the crystal is rotated through a diffracting position. The shape of the transmitted curve has been shown to be thickness dependent. These phenomena have been applied to investigate the extent of perfect single crystal regions within large crystal pieces by studying the dependence of the transmitted intensity near the diffracting position of the perfect single crystal region. For a particular wavelength the transmitted intensity may increase, decrease, or give a maximum—minimum at the Bragg angle, depending on the single crystal region extent. The experiments were performed for LiF crystals and transmission studies were made at Mo$K\alpha_1$ and Cu$K\alpha_1$ wavelengths. Single crystal regions within a large crystal showed the phenomena of extinction, asymmetrical transmission, or anomalous transmission. For the LiF used the results indicated numerous perfect crystal regions, each extending over a few tenths of a millimeter.

* This work is supported by a grant from the National Science Foundation.

H7. Internal Friction of Rocksalt Single Crystals. D. R. FRANKL AND T. A. READ, *Columbia University.*—The internal friction and vibrational strain amplitude of synthetic single crystals of Rocksalt have been measured, by the composite piezoelectric oscillator method, as functions of the applied driving voltage. The internal friction is found to increase nearly reversibly with the strain amplitude at low amplitudes. In some cases, on increasing the driving voltage beyond a certain value, the increase of internal friction was sufficiently great to cause a reduction in the amplitude of vibration; thus, the internal friction is a doubly valued function of strain amplitude. An explanation in terms of motion of dislocations will be proposed. The magnitude of the internal friction is profoundly dependent upon the history of the specimen. In particular, introduction of F centers by x-irradiation at room temperature was found to reduce greatly the internal friction, in some cases making it nearly independent of strain amplitude up to maximum amplitudes as high as 10^{-4}. This is interpreted in terms of diffusion of lattice vacancies and trapping of these by dislocations.

H8. An X-ray Investigation on the Effect of Mechanical Surface Treatment on the Lattice Regularity of Quartz and Calcite. J. C. M. BRENTANO AND T. L. THOURSON,* *Northwestern University.*—Diffraction of x-rays from monochromators with ground surfaces show a line broadening not accounted for by the geometry of the instrument. Miss Armstrong and D'Eustachio[1] found that grinding produces a disturbed layer giving irregular diffraction. According to the former the layer extends over 70μ. We investigated the layer in view of the broadening using a diagonal slit goniometer[2] which separates regularly diffracted radiation from radiation off the Bragg angle. We also used a high resolution goniometer and electron microscopy. For (10$\bar{1}$1) ground quartz faces, 0.38 percent of the diffracted radiation was scattered off the Bragg angle by 2.1°, owing to disoriented crystallites. For calcite, radiation was scattered by more than 3° off the Bragg angle. No crystallite size or strain broadening was detected. For calcite the disoriented blocks measured approximately 500A. Light etching to a depth of 10μ removed the disturbed layer, and the diffraction pattern was then more regular than from a natural face; this required an irreversible reaction which avoids reprecipitation.

* Now with the International Harvester Company, Chicago, Illinois.
[1] E. J. Armstrong, Bell System Tech. J. **25**, 136 (1946); D. D'Eustachio, Phys. Rev. **70**, 522 (1946); also for earlier references.
[2] Brentano, Honeyburne, and Berry, Proc. Phys. Soc. (London) **51**, 668 (1939).

H9. Studies of Gas Adsorption on the (100) Faces of Copper and Nickel Crystals by Low Speed Electron Diffraction.* ROBERT E. SCHLIER† AND H. E. FARNSWORTH, *Brown University.*—The work reported previously[1] has been continued using liquid nitrogen, rather than dry ice and acetone, surrounding the vapor trap between the oil diffusion pump and the experimental tube. The present results differ from the earlier ones. The difference appears to be due to pump oil decomposition products which entered with gas that was admitted through the pump when the trap was at dry ice temperature. As in the earlier work, gas is allowed to adsorb for ten minute intervals. Nitrogen adsorbs on copper in a crystalline monolayer, with pressure at half-coverage being about 3μ, 0.3μ, and 0.05μ, for the crystal at room, dry ice, and liquid nitrogen temperatures, respectively. Most adsorption takes place in the range from $\frac{1}{10}$ to 10 times the pressure at half-coverage. Oxygen adsorbs at pressures as low as 0.0003μ, into a single-spaced face-centered arrangement, at room and dry ice temperatures. Results for nickel and copper under the earlier condition are compared, with nickel adsorbing at 1/100 the pressures required for copper.

* Assisted by ONR and Research Corporation of New York.
† General Electric Coffin Fellow during 1950–1951.
[1] R. E. Schlier and H. E. Farnsworth, Phys. Rev. **78**, 316 (1952).

H10. Enhancement of X-ray-Induced Absorption Bands in Alkaline-Earth Compounds. JAMES H. SCHULMAN, ROBERT J. GINTHER, AND RUSSELL D. KIRK, *Naval Research Laboratory.*—A significant increase is observed in the absorption bands produced by x-irradiation of alkaline-earth compounds

if these compounds are prepared with monovalent positive-ion impurities in solid solution. This observation is consistent with the assumption that the color centers produced by x-rays are associated with negative-ion vacancies and that substitutional solid solution of monovalent cations requires the formation of anion vacancies to preserve electrical neutrality. The observations may also be accounted for by assuming interstitial solid solution of one alkali ion for each such ion dissolved substitutionally, the interstitial ion being an electron trap. The addition of any alkali ion to CaF_2; the addition of sodium ion to $SrCl_2$; and the addition of sodium or potassium ions to $SrSO_4$ were found to be particularly effective in enhancing the x-ray-induced absorption bands, as evidenced by the measurement of the spectral distribution of diffuse reflectivity. The prediction is substantiated that the addition of trivalent cations in any of the above alkaline-earth salts or of monovalent anions in $SrSO_4$ should neutralize the effect of alkali-ion sensitization.

H11. Additive Coloration of Single Crystals of BaO.* WILLIAM C. DASH, *Cornell University*.†—Single crystals of BaO were heated in the presence of Ba vapor at 1000°C for about an hour. The crystals thus treated had a blue color which diminished toward the interior of the crystals in the manner of a diffusion phenomenon. An optical absorption peak occurred at 2.0 ev at room temperature. The peak shifted to about 2.3 ev upon cooling to −160°C. The Ba used contained about 1 percent impurities, mostly other alkaline earth metals. These impurities prompted coloration attempts in vapors of 99.8 percent pure Mg, Baker's "purified" Ca, and also 99.98 percent pure Al. In all cases the crystals turned blue. Absorption measurements at room temperature and at −160°C gave curves similar to those obtained with Ba. These results suggest that the main consequence of the foreign metals is to produce an effective excess of Ba. The coloration might then be caused by Ba in interstitial positions or by negative ion vacancies in the interior formed by oxygen diffusing to the surface.[1]

* This work has received support from the ONR.
† Now at General Electric Research Laboratory, Schenectady, New York.
[1] See following paper (H12).

H12. Oxygen Vacancies in Barium Oxide Crystals.* R. L. SPROULL AND R. S. BEVER, *Cornell University*.—Experiments have been performed which indicate that the principal lattice defects in BaO with a stoichiometric excess of Ba or with electropositive impurities are oxygen vacancies. This conclusion is obtained as follows: The preceding paper by W. C. Dash shows that BaO crystals are colored blue by adding electropositive elements and that the type of defect responsible for the blue coloration is either interstitial Ba or oxygen vacancies. The diffusion of this defect into the BaO crystal has been measured using its optical absorption as a measure of its concentration. The activation energy for diffusion is 2.4±0.2 ev, which is quite different from the activation energies measured by Redington[1] for the motion of Ba^{140} in BaO crystals. The defects therefore move into the crystal by a mechanism which does not transport barium, which means they cannot be interstitial barium. The conclusion is that the defects are oxygen vacancies. The optical absorption is therefore analogous to either the F or F' center in alkali halides.

* This work has received support from the ONR.
[1] R. W. Redington, Phys. Rev. **87**, 1066 (1952).

H13. Dielectric Constants of Solid HCl and HBr. R. H. COLE, R. W. SWENSON, AND N. L. BROWN,* *Brown University*.—Serious errors from sample inhomogeneities have led to conflicting values for these substances in the past. By suitable precautions to minimize formation and development of voids, we have been able to obtain consistent and more readily understandable results. The dielectric constants of solid HCl above 100°K agree with Onsager's equation as do the values for HBr above 117°K, indicating absence of short-range order in the high temperature solid phases of both substances. Below these temperatures, dispersion and loss are found at comparable frequencies which conform to simple rate expressions. The polarization is small in HCl but becomes very large near the 89° transition in HBr.[1] No intrinsic dispersion at audio- or radiofrequencies was found in the high temperature phase of either. Implications of these results will be discussed.

* Now at General Electric Company, Syracuse, New York.
[1] N. L. Brown and R. H. Cole, J. Chem. Phys. **20**, 196 (1952).

THURSDAY AFTERNOON AT 2:00

Fogg Museum

(K. T. BAINBRIDGE presiding)

Apparatus of Nuclear Physics

I1. Double-Focusing by a System of Two Magnets with Nonuniform Fields.* R. M. STERNHEIMER, *Brookhaven National Laboratory*.—Equations have been obtained for the focusing of charged particles by a system of two magnets with nonuniform fields such that $n>0$ in the first magnet and $n<0$ in the second.[1] The system can be described by the equations for a thick lens. It was found that for $|n|\to\infty$ there is one object distance for which double-focusing is obtained. The values of the object and image distances for double-focusing can be varied by changing the lengths or the field gradients of the two sections. This system makes it possible to double-focus particles with energy in the Bev range with conveniently small magnet sections. As an example, 2.5-Bev π-mesons emitted from an object (target) distance of 25 ft can be double-focused at an image (collector) distance of 25 ft with two equal sections of length 22 in. having a magnetic field gradient of 2500 gauss/inch and separated by 13 in. For moderate values of $|n|$ ($\sim$10), deflecting systems can be designed which have a suitable energy dispersion and give double-focusing with small entrance and exit angles.

* Work done under the auspices of the AEC.
[1] Courant, Livingston, and Snyder, Phys. Rev. (to be published).

I2. Response of a Pulsed Geiger Tube. HERBERT B. ROSENSTOCK, *U. S. Naval Research Laboratory*.—For the purpose of extending the usefulness of a Geiger counter to higher radiation intensities, it has been suggested[1] that the voltage applied to its electrodes be a periodically repeated pulse rather than the usual dc. If the duration of the pulse is of the order of the spread time of the discharge in the tube, the output current *vs* radiation intensity relation will differ from the usual linear one, largely because the resulting current surge might not reach its maximum before the end of the applied pulse. This relation will therefore depend, among other factors, on the not fully understood mechanism by which the discharge spreads. Using probability considerations, we here

calculate this relation as a function of the response of the tube under ordinary operation. If the discharge spreads rapidly (e.g., exponentially) initially, an approximate general relationship not involving the detailed spread mechanism may be established. Two cases of slow initial spread, using possibly realistic models for the spread mechanism, are discussed in detail.

[1] S. W. Lichtman, NRL report 4013 (1952); Nucleonics (to be published).

I3. Rotating Condenser for Synchrocyclotron Oscillator.* MARTYN H. FOSS, *Carnegie Institute of Technology.*—The oscillator for the Carnegie Institute of Technology synchrocyclotron is a Hartley type. The transmitting tube plates are at radio frequency ground. The cathode to ground and grid to cathode inductances are obtained by tapping the central conductor of a coaxial line at appropriate distances from its grounded end. The grid to ground capacitance is the remaining structure. This capacitance is varied by a rotating condenser to tune the oscillator from 9 to 16 meters. Since physical size and wavelength are comparable, problems are encountered which resemble uhf problems. Thus the rotating condenser must be regarded as a loaded transmission line along its axis of rotation, i.e., perpendicular to the usual direction of current flow. The capacity loading makes the one-meter toothed portion of the shaft contain three meters of wave. If the equivalent length of the shaft is over 4.5 meters, then it will have a half-wave resonance in the band which may interfere with the performance of the oscillator. The resonant frequency of the shaft is made sufficiently high by carrying coaxial ground structures over the shaft ends to the bearings at a suitable impedance.

* Supported in part by the AEC.

I4. A Ten-Kilocurie Cobalt 60 Source.* W. W. MEINKE, E. W. COLEMAN, J. V. NEHEMIAS, AND L. E. BROWNELL, *University of Michigan.*—A ten-kilocurie cobalt 60 source has been designed for irradiation of foods and pharmaceuticals as well as a study of chemical reactions. It combines accessibility with maximum capacity. It consists of 100 cobalt rods $\frac{1}{4}$ in. in diameter and 10 in. long encased in $\frac{3}{8}$-in. nominal size aluminum 3SH18 pipe. Irradiation in the Chalk River NRX reactor for $4\frac{1}{2}$ months gives 10 kilocuries. The rods are mounted in a double circle $7\frac{3}{16}$ in. i.d. The irradiation chamber for the source consists of a room 8×11 ft with 10-ft high walls of 4-ft thick concrete and a plywood roof. A labyrinthine entrance reduces radiation out the door. A stub wall at one position of the labyrinth allows limited manipulation in the chamber. The source can be "turned off" by lowering into a 16-ft pit of water. Anticipated features include (a) 250 000 rep/hr over area of $6\frac{1}{4}$ in. diameter in center of source; (b) levels from ~200 000 rep/hr outside source to ~5000 rep/hr at wall of radiation room; (c) less than 2 mr/hr for personnel when source is in bottom of pit.

* This program was supported by the AEC and the Michigan Memorial Phoenix Project.

I5. Fast Neutron Film Dosimeter. J. S. CHEKA, *Oak Ridge National Laboratory.*—Nuclear track film has been used for some time to monitor personnel for neutron exposure. A cadmium shielded portion indicates fast neutron exposure by recording recoil protons. The fast exposure so indicated is not proportional to dose unless the energy spectrum of the neutrons detected is the same as that of the source used for calibration. A modification has been developed in the packaging of the films which makes the film response proportional to dose for neutron energies up to 14 Mev. The film response, in tracks/cm^2, comprises three effects: (a) protons >0.25 Mev generated in the emulsion, (b) protons generated in the film base and reaching the emulsion with a residual energy >0.25 Mev, and (c) protons generated in extraneous organic material which reach the emulsion with a residual energy >0.25 Mev. With the present packet, (a) and (b), added, agree fairly well up to about 5 Mev with the tissue dose curve, as calculated by W. S. Snyder. Beyond 5 Mev the contribution of (c) makes the track count too high. By the use of calculated thicknesses of aluminum foil and organic material, (c) can be modified to make the total response proportional to dose.

I6. A Versatile Coincidence Gray Wedge Pulse-Height Analyzer.* R. L. CHASE, W. BERNSTEIN, AND A. W. SCHARDT, *Brookhaven National Laboratory.*—The gray wedge technique of data collection[1] has been utilized to display the amplitude distribution of time coincident pulses. With a relatively simple and easily maintained apparatus one can obtain a photographic presentation of the amplitude spectrum of pulses from one scintillation detector which are in coincidence with pulses of a preselected amplitude from a second detector. The instrument is well adapted to the study of complex decay schemes, and because it is multichannel in character, is particularly valuable when working with short-lived isotopes. It has also been used as a two-crystal Compton spectrometer and as a three-crystal pair spectrometer. The circuit may be used with NaI(Tl) crystals or any of the faster phosphors. It includes a 10^{-7} second coincidence circuit and a single channel pulse-height analyzer which combine in a slow (2×10^{-6} second) coincidence circuit to control the pulse stretching and sweep circuits of a gray wedge amplitude analyzer. The use of two cascaded coincidence circuits makes possible a leisurely amplitude selection on slowly rising pulses without appreciable sacrifice in coincidence resolution. The performance will be illustrated by reference to data taken on I^{131} and Ag^{108}.

* This work was performed under the auspices of the USAEC.
[1] Bernstein, Chase, Slavin, Garfield, and Schardt, Phys. Rev. **86**, 584 (1952).

I7. Gray Wedge Time Delay Analyzer.* A. W. SCHARDT, W. BERNSTEIN, AND R. L. CHASE, *Brookhaven National Laboratory.*—The gray wedge technique has been used to measure time delays in the region from 10^{-8} to 5×10^{-7} second. An analyzer has been built in which the first event triggers a horizontal, blanked sweep parallel to the clear part of the wedge. The second event stops the horizontal sweep, opens the intensifier clamp, and starts a sweep up the gray wedge. On the pictures the horizontal distance corresponds to time delay, the vertical distance to the logarithm of the number of counts. Single channel analyzers are associated with both trigger circuits in order to minimize interference by undesired pulses. This machine can be used in any application where time correlation between pulses coming from one or two detectors is desired, e.g., time of flight or isomeric life time measurements. The exponential decay of an isomeric state gives a straight boundary to the blackened portion of the photograph with a slope determined by the half-life. Satisfactory results have been obtained using an Hf^{181} source and two detectors. The machine also performed satisfactorily with an As^{73} source grown inside a sodium iodide crystal. In this case both signals were taken from one detector using pulse-height analysis to obtain the desired correlation. J. P. Welker *et al.* are reporting in detail on this work.

* This work was performed under the auspices of the U. S. AEC.

I8. A Fast Triple Coincidence Circuit.* FRANCIS M. PIPKIN, SCOTT M. DAUBIN,† AARON LEMONICK, AND DONALD R. HAMILTON,‡ *Princeton University.*—A fast triple coincidence circuit, essentially the same as Garwin's[1] with each 6J6 replace by three 1N56 diodes in parallel, has been used for three months of continuous service in beta-gamma polarization correlation experiments. It was found to be extremely important that the germanium diodes have the same back resistance and carry currents of order 5 microamperes. The resolving time as measured both by pulse delay and chance counting

rate is about 2×10^{-8} sec. For pulser input pulses of 5, 5, 5; 5, 5, 0; 5, 5, 1; 2, 2, 2; 1, 1, 1 volts in the three channels, the output pulses were 26.6, 1.4, 14.0, 12.2, 2.3 volts, respectively; that is triple/double ratio better than 10:1 for a wide range of relative input pulse sizes. For input stilbene crystal plus photomultiplier triple coincidence pulses, the discriminator curve had a long flat plateau of true triples.

* Supported in part by the AEC and Higgins Scientific Trust Fund.
† On leave, U. S. Naval Postgraduate School.
‡ At present at Institute for Advanced Study.
[1] R. L. Garwin, Rev. Sci. Instr. **21**, 569 (1950).

I9. Scintillation Response of NaI(Tl) under Bombardment with Positive Ions of Energies 60 to 600 Kev.* SAMUEL K. ALLISON AND HARVEY CASSON, *University of Chicago.*—In connection with the calibration of a new energy spectrometer, the response of NaI(Tl) under surface bombardment with monoenergetic protons, deuterons, alpha-particles, and neon ions in the energy range 60 to 600 kev has been investigated. Most of the particles used in the calibration were accelerated in a Cockcroft-Walton accelerator, scattered from a gold target, and selected in energy by deflection through 180° in a spherical electrostatic analyzer before impinging on the surface of the scintillator. Two crystals of NaI(Tl) were investigated using an EMI type 5311 photomultiplier and a single channel pulse-height analyzer. Pulse-height *vs* energy curves were obtained showing the response to be linear (within 5 percent) in each case. Whereas the proton, deuteron, and alpha-particle curves when extrapolated to zero pulse-height passed through the origin within the limits of error, the extrapolated neon curve had an energy intercept of approximately 50 kev. Calling the slope of the proton pulse-height *vs* energy curve unity, the relative slopes for the D^+, He^+, and Ne^+ curves were found to be 0.98, 0.75, and 0.54, respectively.

* This work was supported in part by the AEC.

I10. Analyzing Magnet.* R. F. MOZLEY AND H. BICHSEL, *Princeton University.*—A magnet has been constructed for energy analysis of the external proton beam of the Princeton 18-Mev cyclotron. For accurate analysis rectangular pole pieces with a uniform gap of 1 in. over an area 20 in.×8 in. are used. Fields uniform to 0.1 percent can be obtained over an area of 18 in.×6 in. at field strengths of up to 10 000 gauss. Since the pole pieces are nonfocusing in the horizontal plane, the energy can be determined from the angle through which the beam is bent by the fringing and internal fields of the magnet without knowledge of the exact path of the beam. With the present system the energy resolution is ±0.2 percent and the expected final accuracy of energy determination better than 0.5 percent. The magnet is being used to determine the energy spectrum of the cyclotron beam for use in the analysis of scattering experiments, and to obtain protons of accurately known energy for use in determining the range-energy relationship. Wedge-shaped double focusing pole tips can be installed to permit more efficient analysis where intensity is of more importance than energy determination.

* This work was supported by the AEC and the Higgins Scientific Trust Fund.

I11. The Range of Protons in Aluminum.* H. BICHSEL AND R. F. MOZLEY, *Princeton University.*—Protons of various energies up to 18 Mev are obtained using an analyzing magnet in the external beam of 18-Mev protons from the Princeton cyclotron. Absorbers of appropriate thickness can be used to reduce the beam energy to the approximate value required. The analyzing magnet and collimation system select the exact value desired. An aluminum foil of known thickness is placed between two proportional counters through which the analyzed protons pass. To determine the mean range, individual protons are counted in both counters and the energy of the incident protons is adjusted to produce a counting rate in the second counter one-half that in the first. The two counters are made in one envelope thus requiring only one entrance window. This is made of 1.5 mg cm^{-2} aluminum and the energy loss in the counter gas is approximately 50 kev. A preliminary determination gives a range of 343.5±1 mg cm^{-2} at a beam energy of 15.00±0.2 Mev. Work is in progress to improve the accuracy of the measurements and to obtain the range at other energies.

* This work was supported by the AEC and the Higgins Scientific Trust Fund.

THURSDAY AFTERNOON AT 2:00

Pierce 110

(D. J. HUGHES presiding)

Neutron Physics, I

J1. Resonance Scattering in Indium.* L. B. BORST, *University of Utah.*—A scattering tube was inserted into the Brookhaven reactor in such a way that neutrons scattered from a thin sample within the reactor could be studied as a bright neutron source. The scattering spectrum of indium was studied by two methods. (1) The total spectrum was analysed by self-activation, self-absorption, and critical absorber techniques. (2) The 1.46-ev resonance was analyzed using a Cauchois-type bent crystal spectrometer using the 100 plane in sodium chloride. Curves in the first and second order were obtained for the source intensity (σ_{sc}), transmission (σ_t), and activation (σ_c). No evidence was found of displacement of the scattering resonance with respect to the total or capture resonances.

* Work performed at Brookhaven National Laboratory, Upton, New York, under auspices of the AEC.

J2. Paramagnetic Scattering of Neutrons by the Trivalent Ions of Nd and Er. W. C. KOEHLER AND E. O. WOLLAN, *Oak Ridge National Laboratory.*—A study has been made of the paramagnetic scattering by the trivalent rare earth ions Nd^{+++} with three 4-*f* electrons in the state $^4J_{9/2}$ and Er^{+++} with three 4-*f* vacancies in the state $^4J_{15/2}$. Up to the present no experimental or theoretical studies have been made of the scattering effects from ions having large orbital contributions to their magnetic moments. Scattering measurements with 1.16A neutrons were made from 3° to 90° in scattering angle at room temperature and at the temperatures of liquid nitrogen and liquid hydrogen. No significant change with temperature of the paramagnetic scattering was observed. The forward scattering was found to be proportional within experimental error to $\mu_{eff}^2=g^2\beta^2J(J+1)$. The magnetic scattering by Nd^{+++} which depends in a complicated way on the differ-

ence of the orbital and spin moments falls off very much less rapidly with angle than the scattering by Er^{+++} which depends on the sum of orbital and spin moments. The general features of the two scattering curves can be accounted for on a simple Bohr orbit picture. Progress toward a rigorous theoretical treatment of this problem is reported in the next abstract.

J3. Elastic Scattering of Neutrons from Paramagnetic Rare Earth Atoms. G. T. TRAMMELL, *Oak Ridge National Laboratory.*—The calculation of the magnetic scattering cross section of paramagnetic ions for slow neutrons involves complicated integrations over angles when the ions have nonzero orbital moments. We resolve the relevant operators which appear in the Born approximation for the elastically scattered waves into their irreducible tensor parts. Assuming Russell-Saunders coupling, these operators are transformed into irreducible tensor operators involving **J** by means of the Wigner-Eckart theorem and an expression for the cross section obtained which involves only radial integrals over the atomic charge distribution. Numerical examples will be given of the similar systems Nd^{+++} (3 4-*f* electrons $L=6$, $S=3/2$, $J=9/2$) and Er^{+++} (11 4-*f* electrons $L=6$, $S=3/2$, $J=15/2$) studied experimentally by Koehler and Wollan.

J4. The Energy Distribution of Slow Neutrons Scattered in Crystals.* DAVID A. KLEINMAN, *Brookhaven National Laboratory.*—The energy distribution cross section $\sigma(E_0, E)$ for scattering from an incident energy E_0 into a unit energy interval at energy E is given in the incoherent approximation by the formula

$$\sigma(E_0, E)=\bar{\sigma}(8\pi\theta)^{-1}e^{\epsilon\xi}\int_{-\infty}^{\infty} dZe^{i\epsilon Z}\{e^{-\alpha\Psi(Z)}-e^{-\beta\Psi(Z)}\}/\Psi(Z), \quad (1)$$

where θ is the Debye temperature, the temperature of the crystal is

$T=\theta/2\zeta$, $\epsilon=(E_0-E)/\theta$, $\alpha=[1-(E/E_0)^{\frac{1}{2}}]^2$, $\beta=[1-(E/E_0)^{\frac{1}{2}}]^2$,

$\bar{\sigma}$ is the bound scattering cross section, and $\Psi(Z)$ is the function

$$\Psi(Z)=3(m/M)(E_0/\theta)\int_0^1 xdx[\cosh x\zeta-\cos xZ]/\sinh x\zeta. \quad (2)$$

Saddle point and expansion methods have been found by which (1) can be evaluated for any value of E_0. The expansion has as its first term the usual single phonon approximation to the inelastic scattering. Calculations have been made on beryllium at temperature $T=\theta$ showing how the scattering transforms continuously from free atom scattering at high energy to single phonon scattering at low energy.

* Work done under the auspices of the AEC.

J5. Measurements of Neutron Capture γ-Rays with a Scintillation Spectrometer. T. H. BRAID, *Chalk River Laboratory.*—A two-crystal scintillation spectrometer of the Hofstadter type has been used to measure the energies and intensities of γ-rays in the range 0.3 Mev to 3 Mev. A single peak is obtained at all energies by the use of stilbene for the analyzing crystal. Standardized sources have been used to establish energy and sensitivity calibrations. Neutron capture γ-rays have been observed from samples placed near the reacting vessel of the Chalk River pile. The energies and intensities of the γ-rays from 23 elements have been measured. In particular the following γ-rays have been observed.

Sodium	0.48,	0.86,	1.34,	1.66,	2.0 Mev.
Phosphorus	0.51,	1.13,	2.23 Mev.		
Sulphur	0.84,	1.52,	2.34 Mev.		
Chlorine	0.48,	.75,	1.14,	2.45,	2.84 Mev.
Titanium	0.33,	1.4 Mev.			

J6. Gamma-Rays Produced by Neutron Capture in Cd^{113}. G. A. BARTHOLOMEW AND B. B. KINSEY, *Chalk River Laboratory.*—The γ-rays from the $Cd^{113}(n, \gamma)Cd^{114}$ reaction have been measured with an improved pair spectrometer (resolution 100 kev). The γ-rays of highest energy are tabulated below:

γ-ray	Energy Mev	Absolute intensity (percent)
A	9.046 ± 0.008	0.14
B	8.483 ± 0.008	0.23
C	7.841 ± 0.010	0.12
D	7.726 ± 0.010	0.16
E	7.665 ± 0.010	0.21
F	6.820 ± 0.013	0.36

The energy difference, 0.563±0.008 Mev, between γ-rays *A* and *B* is equal to the known energy of the first Cd^{114} level. Since, moreover, no γ-rays were observed above *A*, we conclude that the neutron binding energy of Cd^{114} is 9.046 Mev. A level scheme for Cd^{114} based on the observed γ-rays will be presented and compared with levels deduced from the decay of In^{114}. The partial radiative widths of the γ-rays may be obtained from the known total width (0.115 ev) of the Cd^{113} resonance and the absolute intensities. These widths will be compared with current theoretical predictions of radiative transition probabilities.

J7. Gamma-Radiation from Interaction of 14-Mev Neutrons with Matter. W. R. FAUST, V. E. SCHERRER, AND R. B. THEUS, *Naval Research Laboratory.*—Neutrons from the $T^3(D, n)He^4$ reaction bombarded a converter arranged so that whenever a neutron entered the converter, an alpha-particle entered the accelerator monitor. The pulse-height distribution from converter gamma-rays was observed by a scintillation spectrometer consisting of a single crystal of NaI(tl) and a twenty-channel pulse-height analyzer. Coincidences between the crystal pulses and alpha-monitor were used to trigger the pulse-height analyzer so that only gamma-rays produced by neutrons in the converter were counted. Pulse-height distributions were observed for converters of carbon, oxygen, aluminum, iron, copper, and lead. A possible interpretation of the data indicates that there may be a low energy continuum overlaid by a series of lines or bands at higher energies. Calculation of the cross section for gamma-ray production indicates that it may be from one to several times the corresponding cross section for inelastic neutron scattering for all elements.

J8. Prompt Gamma-Rays from Slow Neutron Capture.* HENRY T. MOTZ, *Brookhaven National Laboratory.*—The prompt gamma-ray spectra in the region of 300 kev to about 1.5 Mev have been studied for sodium and cadmium irradiated by slow neutrons. Several experimental arrangements using a collimated gamma-ray beam in conjunction with a thin lens beta-ray spectrometer have been used: (a) Th and U converters to observe the photoelectric conversion lines, (b) a NaI scintillation detector to count the coincidences of *K* x-rays from the converter with the conversion electrons, and (c) Be radiators to observe the Compton electron spectra. Four lines have been found from $Cd^{113}(n, \gamma)Cd^{114}$ having energies of 555±5, 646±9, 802±15, and 1299±15 with intensities of 0.89±0.10, ~0.3, ~0.1, and ~0.5 gammas per neutron capture. The first and fourth of these correspond to known gammas of Cd^{114}.[1] Two lines have been measured from $Na^{23}(n, \gamma)Na^{24}$. These have energies of 475±10 kev and 877±10 kev, each with an intensity of 0.40±0.10. The 475-kev line corresponds to the first excited level of Na^{24} found from the $Na^{23}(d, p)Na^{24}$ reaction,[2] and the sum of the two lines corresponds to the third excited level.

* Research carried out under contract with the AEC.
[1] Johns, Cox, Donnelly, and McMullen, Phys. Rev. **87**, 1134 (1952).
[2] A. Sperduto and W. W. Buechner, Phys. Rev. **88**, 574 (1952).

J9. On Stars Initiated by Neutrons.* R. W. WANIEK AND T. OHTSUKA.—Bombarding a Be target with the high energy protons from the internal beam of the 95-in. Harvard synchrocyclotron, different neutron spectra are obtained at

various angles from the direction of incidence.[1] Two nuclear track plates, Ilford G5 200μ, were exposed simultaneously to well-collimated neutron beams, the one at 0° and the other at 14° from the target. The neutron spectrum at 0° shows a prominent peak at high energies which is not present at all in the 14° spectrum. The experiment which was performed under "good geometry" conditions aimed at the irradiation of the plates by neutrons of two effective energies. About 400 stars were scanned for each plate, localizing the prongs in space and measuring their actual ranges. Spatial angular distributions and range histograms will be presented for all the events together as well as for each type of star separately. The differences in the results from the two plates is attributable to the interaction of the high energy neutrons, obtained by subtracting the two spectra (peak at 90 Mev, half-width 25 Mev), with the nuclei of the emulsion.

* Supported by the ONR and AEC.

[1] K. Strauch and J. A. Hofmann, Phys. Rev. **86**, 563 (1952).

THURSDAY AFTERNOON AT 2:00

Allston Burr, A

(JULIAN SCHWINGER presiding)

Various Topics in Theoretical Physics

JA1. Elementary Particle Structure.* ROGER E. CLAPP, *Cambridge, Massachusetts.*—Atoms, nuclei, and elementary particles have in turn been thought ultimate and indivisible. This historical sequence may possibly terminate in the concept of a single primitive wave field, from which all elementary particles are to be constructed. On the assumption that such a primitive field has zero rest-mass and a spin of one-half, equations have been written to describe systems of two or more primitive waves, interacting only through the exclusion principle, and eigenfunctions have been found for some of the simpler equations. For example, the wave equation for the system of two primitive waves may be satisfied by eigenfunctions of spin one and of spin zero. As a general boundary condition, it has been found suitable to require that structures be resolvable into primitive waves all having the same magnitude of wavenumber, a quantity denoted by κ. A discrete spectrum of masses, or rest frequencies, is found, with the product κc (where c is the velocity of the primitive waves) serving to fix the frequency scale. Frequency ratios are calculated as numbers, without adjustable constants, and may be compared with experimental mass ratios. Numerical results will be given at the meeting.

* Research supported by ONR contract.

JA2. On the Concept of a Physical Object. JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories.*—Viewed operationally, a physical object or system is essentially the conceptual carrier of a set of states. A state is the result of a maximal observation, i.e., such that further information about the system is either superfluous or contradictory. Measurement generally yields less than maximal information, with a subset of the set of states compatible therewith (mixture). Operations preserving the permanence and identity of the object ("admissable operations") transform the set of states into itself; the object can be characterized as the invariant of a group of admissable transformations. Klein's famous group-theoretical characterization of a geometry (study of invariants of some transformation group) thus leads to "geometrization" of physics deeper than that of relativity (and including it). Also (a) information about a system corresponds to a probability distribution over the set of states, with states analogous to unit vectors, (b) an admissable operation merely changes the distribution, i.e., changes the coefficients of the unit vectors, whence (c) any operation is to analogous the matrix representing a linear vector function. Geometrization of physics and association of operators with observables therefore stem from the concept of a physical object rather than relativity and quantum mechanics.

JA3. The Kinds of Energy. JOHN Q. STEWART, *Princeton University.*—Six dimensions were suggested[1] as necessary and sufficient for classical physics. We now relate them to corresponding kinds of energy. Such catalogs permit description of physical phenomena in the most general terms, and also set forth the thinking of physical science as a model for social science, with "values" replacing "energies." Classical physics studies kinetic energy (emphasized by Leibniz), energy of elastic deformation, gravitational energy, heat, chemical energy, and electromagnetic energy. Changes in each are the integral of the product of an intensive factor into an infinitesimal extensive factor. Pairs of factors are, respectively, velocity, momentum; force, distance (or the like); gravitational potential, mass; temperature, entropy; chemical potential, moles reacting; electric potential, charge. One dimension can be chosen from each pair. In any transformation of energy from one to another of its forms, mechanical work (macroscopic or conceptually microscopic) perhaps always is a necessary go-between in our explanations; but work differs from other kinds in being a manifestation, not a store, of energy. Exact correspondences among equations of various branches of physical science are shown to extend much farther than indicated above—particularly between equations of mechanics and electromagnetism.

[1] John Q. Stewart, Phys. Rev. **87**, 197 (1952).

JA4. On Gravitational Radiation.* JOSHUA N. GOLDBERG,† *Syracuse University.*—Infeld and Scheidegger[1,2] have shown that one can always transform away an arbitrary function of time which is introduced into the so-called *radiation terms* of the Einstein-Infeld expansion of the gravitational potentials. They conclude that gravitational radiation does not exist within the framework of this approximation procedure. This conclusion is valid for the longitudinal, but not for the transverse-transverse components. By considering the energy-momentum pseudo-tensor for the gravitational field one finds that introducing an arbitrary function of time in order $(2k+1)$ (transverse-transverse component) yields radiation in order $(4k+7)$ for a pure radiation field and in order $(2k+6)$ for a radiation field interacting with mass points. As a result the equations of motion for mass points in a radiation field should be affected in order $(2k+7)$. Transforming away the arbitrary function of time in order $(2k+1)$ does not affect the gravitational radiation nor the equations of motion in higher orders. This procedure can be carried out without introducing new singularities at any stage.

* Supported in part by the ONR at Syracuse University.
† Now at Armour Research Foundation, Chicago, Illinois.

[1] L. Infeld and A. E. Scheidegger, Canadian J. Math. **3**, 195 (1951).
[2] A. E. Scheidegger, Phys. Rev. **82**, 883 (1951).

JA5. Generalization of the New Classical Electrodynamics. M. AVRAMY MELVIN, *Florida State University.*—The first, special, form of Dirac's recent theory[1(a)] may be called *the superconductive theory:* it is equivalent to the (relativistic) London theory of pure superconductivity (with a special gauge). Since not all electrodynamics is superconductive, this theory is insufficiently general. However, it is readily verified that its equations are already those of a generalized vector meson theory (i.e., with variable rest-mass). This, together with the possibility that upon suitable quantization the discreteness of charge and mass will emerge, suggests that generalizations of the new theory may indeed provide a unitary basis for electrodynamics and mesodynamics. The second, more general form of the theory [1(b)] may be called the *uniform stream theory* since the charge-mass ratio is everywhere uniform. In this theory there is no nontrivial electrostatics; for instance, it is not possible to describe a charged dielectric as a static system. For this reason, and because more than one kind of elementary particle should appear upon quantization, one is led to generalize the theory by allowing nonuniformity of the charge/mass. The consequences of this *general stream theory* will be discussed.

[1] P. A. M. Dirac, (a) Proc. Roy. Soc. (London) **A209**, 291 (1951). (b) Proc. Roy. Soc. (London) **A212**, 330 (1952).

JA6. Special-Relativistic Linear Theory of Gravitation. F. J. BELINFANTE AND J. C. SWIHART, *Purdue University.*—A classical theory of gravitation is derived by independent variation of $h_{\mu\nu}=h_{\nu\mu}$, x_i^μ, $p_{i\mu}$, and A_i^μ in $\delta\int dt(L_g+L_m)=0$, where

$$L_g=-(c^4/16\pi G)\int d^3\mathbf{x}\,g^{\alpha\beta}g^{\lambda\mu}g^{\rho\sigma}[a(\nabla_\alpha h_{\lambda\rho})(\nabla_\beta h_{\mu\sigma})+b(\nabla_\lambda h_{\alpha\mu})(\nabla_\rho h_{\sigma\beta})+f(\nabla_\alpha h_{\lambda\mu})(\nabla_\beta h_{\rho\sigma})+q(\nabla_\alpha h_{\lambda\mu})(\nabla_\rho h_{\beta\sigma})];$$

$$L_m=\Sigma_i[-m_ic^2B_i+p_{i\mu}dx_i^\mu/dt-cp_{i\mu}A_i^\mu+Km_ic^2g^{\lambda\mu}h_{\lambda\mu}(x_i)B_i+\tfrac{1}{2}cCg^{\lambda\mu}h_{\nu\lambda}(x_i)A_i^\nu p_{i\mu}];$$

$$B_i=(-g_{\mu\nu}A_i^\mu A_i^\nu)^{\frac{1}{2}};\quad g_{\alpha\beta}=g^{\alpha\beta}=(1-2\delta_{\alpha 0})\delta_{\alpha\beta}.$$

If the numerical coefficients a, b, f, q, C, K are chosen to satisfy $a(b+2q)/C=(q^2+2aq-4bf)/8K=(2Cb+3Cq-4Kb)/4=(2Kb+Cq)/5$ (thence $=(5q+2b)C/14=2b(5K-C)/11$), then the gravitational field around a static point particle is spherically symmetric and approximately Newtonian, and the advance of the perihelion of a planet is that given by general relativity. For Dirac particles we take

$$L_m=\int d^3\mathbf{x}\psi^\dagger\{-mc^2\beta+i\hbar\partial/\partial t+ihc\boldsymbol{\alpha}\cdot\boldsymbol{\Delta}+Kmc^2g^{\lambda\mu}h_{\lambda\mu}\beta-\tfrac{1}{4}ihcCg^{\lambda\mu}\alpha^\nu(h_{\nu\lambda}\nabla_\mu+\nabla_\mu h_{\nu\lambda})\}\psi.$$

The interaction involves time-derivatives ($\nabla_0=\partial/c\partial t$); so the probability density is not $\psi^\dagger\psi$ but $\psi^\dagger\rho_{\rm op}\psi$ involving a density function $\rho_{\rm op}=1+\frac{1}{2}Ch_{0\mu}\alpha^\mu$ dependent on the gravitational field. Expectation values and the four-current are defined. For a wave packet traveling as a planet around the sun, the approximate equations of motion for the average values $\int\psi^\dagger x^\mu\rho_{\rm op}\psi d^3\mathbf{x}$, $-\frac{1}{2}i\hbar\int\psi^\dagger(\rho_{\rm op}\nabla_\mu+\nabla_\mu\rho_{\rm op})\psi d^3\mathbf{x}$, $\int\psi^\dagger\alpha^\mu\psi d^3\mathbf{x}$, and $\int\psi^\dagger\beta\psi d^3\mathbf{x}$ are the same as those for x_i^μ, $p_{i\mu}$, A_i^μ, and B_i in the classical theory.

JA7. Pair Production by a Curved Metric. BRYCE S. DEWITT, *University of California, Livermore.*—A scalar field in an arbitrary space-time mainfold is considered. If no scalar particles are initially present and the metric is flat, no particles will appear in the course of time. A vacuum remains a vacuum. If, however, the metric departs from flatness in certain regions, one has an impressed gravitational field which can produce particle pairs through its interaction with the vacuum fluctuations of the scalar field. If the metric varies slowly enough so that no real pairs are created, there still remains a nonvanishing stress-energy tensor in the nonflat regions. The phenomenon is analogous to the vacuum polarization effect of electrodynamics. The calculation of this effect involves treating the departure of the metric from flatness as a perturbation, and one is led to familiar divergent integrals. Certain of these integrals can be discarded by requiring that a transformation of coordinates not alter the induced stress. The covariant divergence of this stress then vanishes and one obtains an unambiguous, though divergent, result. The divergent part *cannot* be interpreted as a simple mass renormalization since it is proportional not only to the impressed mass-stress which produced the gravitational field, but also to its space-time derivatives.

JA8. Self-Consistency of Lagrangian Quantization.* PETER G. BERGMANN, *Syracuse University.*—In a paper being published now we have conjectured that in the Lagrangian quantization the field equations should be obtained by the requirement that the action operator be stationary with respect to invariant infinitesimal variations. The resulting number of field equations is usually twice the number of variables in configuration space, so that their mutual compatibility is not obvious. However, it is possible to show that our field equations satisfy a number of identities, because of the group character of the invariant transformations, sufficient to insure compatibility. The commutation relations between the field variables follow from the general principle that each constant of the motion generates its corresponding infinitesimal invariant transformation.

* Supported by the ONR.

JA9. Spin and Statistics of a General-Relativistic Dirac Field.* ROBB M. THOMSON AND PETER G. BERGMANN, *Syracuse University.*—In Lorentz-covariant field theories, the (Fermi-Dirac) statistics of fields with half-odd spin has been derived either from the requirement that the total energy (without interaction) be positive definite or, for charged fields, from the requirement that the theory be invariant with respect to charge conjugation.[1] Under charge conjugation, the electromagnetic field and the charge-current density change sign while the dynamical variables such as energy and momentum do not. In a theory in which rectilinear coordinate systems are not well defined, the Fourier decomposition, which provides the foundation for the formulation of "free" particles and their associated energy levels, is not a natural procedure; hence the first derivation appears incapable of generalization. However, the concept of charge conjugation is readily transferred to general-relativistic theories. It will be shown that in such theories, too, fields with spin $\frac{1}{2}$ obey Fermi-Dirac statistics.

* Supported by the ONR.
[1] W. Pauli, Phys. Rev. **58**, 716 (1940).

JA10. Quantum Effects in Noise.* J. WEBER, *University of Maryland.*—Field quantization is applied to an electrical oscillating circuit. Quantum effects occur both in the damping and in the noise. An interpretation is given of the infinite zero point contribution which appears in the theory of Callen and Welton.[1] The mean squared noise voltage which would be measured in an experiment with an oscillating circuit with capacitance C, and inductance L, coupled to a conductance at temperature T is

$$\overline{V^2}=\frac{1}{C}\left[\tfrac{1}{2}\hbar\omega+\frac{\hbar\omega}{e^{(\hbar\omega/kT)}-1}\right]=\frac{\Delta\omega}{G}\left[\tfrac{1}{2}\hbar\omega+\frac{\hbar\omega}{e^{(\hbar\omega/kT)}-1}\right],$$

where $\Delta\omega$ is the classical breadth and G is the conductance. The maximum noise power which a conductance G at temperature T can transfer to a damped oscillator approaches the value

$$P_{\max}\to\frac{G\hbar\omega}{C[e^{(\hbar\omega/kT)}-1]}=\frac{\hbar\omega\Delta\omega}{e^{(\hbar\omega/kT)}-1}.$$

* Supported by the ONR.
[1] Callen and Welton, Phys. Rev. **83**, 34 (1952).

JA11. Radiation Emitted by Uniformly Moving Particles.* K. TANAKA, *Argonne National Laboratory.*—The peculiar asymmetric radiation by an electron moving in an optically isotropic body with velocity that exceeds that of light in the medium was observed by Cerenkov and the theory was worked out by Frank and Tamm.[1] The problem for uniformly moving particles is solved in general and the results are applied to electrons, protons, and neutrons. Maxwell equations are solved, expanding the field variables in four-dimensional Fourier series, and then calculating the radial component of the Poynting vector in terms of the generalized current density. Then the total energy radiated by the particle is found. The ratio of Cerenkov radiation for neutrons compared to charged particles is found to be negligible.

* Based on work done at the University of California.
[1] I. Frank and I. Tamm, C. R. Acad. Sci. URSS **14**, 109 (1937). I. Tamm, J. Phys. USSR **1**, 439 (1939).

FRIDAY MORNING AT 9:00

Sanders Theatre

(J. H. VAN VLECK presiding)

Business Meeting of the American Physical Society

FRIDAY MORNING AT 10:00

Pierce 110

(E. BRIGHT WILSON presiding)

Invited Paper

K1. Magneto-Resonance and Magnetic Optics. FRANCIS BITTER, *M.I.T.* (30 min.)

Magnetic Resonance; Molecules

K2. Indirect Interaction between Nuclear Spins in Copper Acetate. A. ABRAGAM, *Harvard University* (introduced by J. H. Van Vleck).—An extension of the theory given by Ramsey and Purcell[1] has been made to copper acetate where this interaction should be much larger than in all cases reported so far. According to Bleaney,[2] the electronic spins of two neighboring copper ions are coupled together by exchange interaction, with a ground state $S=0$ and an excited state $S=1$, 315 cm^{-1} above the ground state. The indirect interaction between the nuclear spins of the ions is expected to be anisotropic, of the form $AI_zI'_z$, where z is the axis of the crystalline electric field and $A\sim 3$ kev. This interaction would lead to a fine structure of the nuclear resonance lines in the diamagnetic state, with contributions from both like and unlike nuclei, in contrast to Ramsey and Purcell's case where only unlike nuclei contribute to the fine structure.

[1] N. F. Ramsey and E. M. Purcell, Phys. Rev. **85**, 143 (1952).
[2] Bleaney, Proc. Roy. Soc. (London) **214**, 451 (1952).

K3. High Resolution of Nuclear Resonance Signals in Flowing Samples. A. L. BLOOM AND J. N. SHOOLERY, *Varian Associates.*—It has been shown[1] that the maximum available nuclear resonance signal in a liquid sample can often be increased considerably by flowing the previously polarized sample through the radiofrequency probe Basically, the effect of the motion is to limit the length of time radiofrequency acts on the sample and thus artificially shorten T_1 to be more nearly equal to T_2. We have investigated experimentally the extent to which signal-to-noise may be increased by use of this method in high resolution analysis, keeping the flow rate slow enough so that the resolution is not destroyed by artificial broadening. For chemical shifts in simple organic compounds, of the order of 10 milligauss, a significant improvement in signal-to-noise appears to be possible. For spin-spin interactions,[2] however, the increase in signal is difficult to obtain and is of questionable advantage unless T_1 is very long.

[1] G. Suryan, Proc. Indian Acad. Sci. **A33**, 107 (1951).
[2] N. F. Ramsey and E. M. Purcell, Phys. Rev. **85**, 143 (1952).

K4. Saturation Effects in Paramagnetic Resonance Absorption and the Spin-Lattice Relaxation Time.* A. H. ESCHENFELDER† AND R. T. WEIDNER, *Rutgers University.*—Saturation effects have been observed in the paramagnetic resonance absorption of 3.2-cm microwaves by diluted samples of iron ammonium alum and chromium potassium alum at 2 to 4°K. For all samples the spin-lattice relaxation time, T_1, was found to vary inversely with the temperature, in agreement with theoretical expectation that the direct rather than the "Raman" process for the spin-lattice quantum transfer predominates at helium temperatures. Diluted samples of iron ammonium alum with iron to aluminum atom ratios of 1:18, 1:59, and 1:80 showed T_1 to be essentially independent of dilution and yielded $TT_1=5\times10^{-4}$ sec °K for the well-resolved transition $m=\frac{1}{2}\rightarrow-\frac{1}{2}$. The low-field side peak in the iron spectrum for the (100) orientation, comprised of two unresolved transitions, yielded an effective value of $TT_1=1.4\times10^{-3}$ sec °K. The $m=\frac{1}{2}\rightarrow-\frac{1}{2}$ transition for diluted chromium alum with a chromium to aluminum atom ratio of 1:10 yielded $TT_1=3\times10^{-3}$ sec °K. In all samples the spin-spin relaxation time was found to be temperature independent and of the order of 10^{-5} sec. The results for T_1 are at variance with those obtained with low frequency paramagnetic relaxation experiments, which show a faster temperature dependence than T^{-1} and an increase in T_1 with dilution.

* This work has been supported by the ONR, by the Rutgers University Research Council, and by the Radio Corporation of America.
† Now at I. B. M. Corporation, Poughkeepsie, New York.

K5. Temperature Dependence of the Ferromagnetic Resonance in a (Ni−Fe) Alloy. J. A. COWEN AND R. D. SPENCE, *Michigan State College.*—The temperature dependence of the ferromagnetic resonance line width in a 50 percent nickel-iron alloy (Deltamax) has been measured from 20°C to the Curie point. The samples[1] consisted of thin strips with their surface the (001) plane. The measurements were made at 3.2 cm by the conventional reflection techniques. The line width at room temperature is rather narrow compared to that obtained in most conducting materials and shows a limited anisotropy shift and broadening.

[1] Samples furnished by the Allegheny Ludlum Steel Corporation.

K6. Classical Model for Rotational Magnetic Moments in Molecules.* C. K. JEN, *Applied Physics Laboratory, The Johns Hopkins University.*—Besides supplying the basis for the quantum mechanical formulation,[1-4] the classical theory for rotational magnetic moments in molecules is useful for elucidating physical description. The generalized theorem of Larmor pertaining to molecules, first applied to the problem by Wick,[1] follows directly from the equations of motion for a rotating molecule in magnetic field. It is shown from this theory that purely "rigid" rotation (electronic motion relative to nuclear frame being unperturbed by rotation) of the electrons in a rotating molecule is physically impossible in the general case. Moreover, the rotational magnetic moment of molecular electrons can be considered to consist of two parts, one due to rigid motion together with the nuclear frame and the other to "nonrigid" motion within the frame. The nonrigid motion of the electrons in a rotating molecule is intrinsically associated with the Coriolis torque acting on the moving electrons.

* Supported by Bureau of Ordnance, U. S. Navy.
[1] G. C. Wick, Z. Physik **85**, 25 (1933); Phys. Rev. **73**, 51 (1948).
[2] N. F. Ramsey, Phys. Rev. **87**, 1075 (1952) and earlier papers.
[3] C. K. Jen, Phys. Rev. **81**, 197 (1951).
[4] J. R. Eshbach and M. W. P. Strandberg, Phys. Rev. **85**, 24 (1952).

K7. On the Vibration-Rotation Band System of OH in the Near Infrared. G. DÉJARDIN, J. JANIN, AND M. PEYRON, *Université de Lyon.*—The vibration-rotation bands of OH appear in the spectrum of the oxy-acetylene flame, and are particularly distinct if a moderate excess of oxygen is used. This spectrum has been studied in the near infrared (7500–9500A) with a grating spectrograph (20 A/mm) and suitable plates. The rotational structure of the OH bands 4−0, 5−1, and 6−2 was resolved in the P, Q, and R branches. The observed wave numbers are in very good agreement with the predictions of the formula of Hill and Van Vleck, taking into account the rotational constants given by Dieke and Crosswhite and admitting, for the upper vibrational levels, the values $B_4=15.729$, $B_5=15.050$, $B_6=14.378$, and $D_{4,5,6}=0.00182$. There is a variable difference of several angströms between the wavelengths, which are accurate within 0.2A, and those previously measured in airglow spectra, the latter being the highest. The values of the spin doublet splitting obtained for the levels $v=4$, 5, and 6 are fairly consistent with the theory of Hill and Van Vleck. The Λ-type doubling was also observed on the P_1 lines ($^2\Pi_1$ state) corresponding to high rotational quantum numbers; the experimental term splitting is well represented by the formula $\Delta F=qK(K+1)$, the constant q being equal to 0.032 for $v=4$ and to 0.029 for $v=5$, in conformity with the theory of Kronig and Van Vleck for the Hund's case (b).

K8. Vibrational Emission Spectra in Glow Discharges. FRANK MATOSSI, *U. S. Naval Ordnance Laboratory.*—The molecular emission spectra recently discovered in glow discharges[1] will be interpreted as excited by collisions of molecules with slow ions or electrons accelerated by the electric field. In order to prevent the charged particles from gaining too much energy, a certain critical pressure is necessary. This pressure depends on temperature and vibration frequency. It is assumed that only the difference between vibration energy and thermal energy must be balanced by the energy gained in the field. New observations will be reported and discussed.

[1] Talley, Lowe, and Scanlon, Phys. Rev. (to be published).

K9. Absorption Coefficients of O_2 in the Vacuum Ultraviolet. K. WATANABE, EDWARD C. Y. INN, AND MURRAY ZELIKOFF, *Geophysics Research Directorate.*—Absorption coefficients, k, of O_2 in the region 1050–1900A were obtained with a Baird 1-meter monochromator, a hydrogen source, and a phosphor-coated $1P21$. The absorption cell (0.47 cm) with LiF windows was placed at the exit slit (band width 0.85A) and pressures from 0.1 to 500 mm were used. For the Schumann continuum k-values were found to be somewhat lower than previous data[1]; e.g., the maximum k was 380 cm^{-1} at 1420A in contrast to about 490 cm^{-1} at 1450A. The continuum was rather asymmetric, the shorter wavelength slope being quite steep and superposed with three diffuse bands. Absorption coefficients will be presented also for the regions 1050–1330A and 1670–1850A. At Lyman alpha our result agreed with Preston's[2] measurement. Absorptions of H_2 and N_2 were made in the region 1050–1500A. Lyman bands and Birge-Hopfield forbidden bands were observed, but no continuum could be detected for pressures up to 500 mm.

[1] R. Ladenburg and C. C. van Voorhis, Phys. Rev. **43**, 315 (1933).
[2] W. M. Preston, Phys. Rev. **57**, 887 (1940).

K10. Absorption Coefficients of N_2O and CO_2 in the Vacuum Ultraviolet. MURRAY ZELIKOFF, EDWARD C. Y. INN, AND K. WATANABE, *Geophysics Research Directorate.*—Absorption coefficients, k, of N_2O and CO_2 in the region 1050–2000A were obtained using the apparatus described in the previous paper. For N_2O, four continua were observed with maxima at 1820A, 1448A, 1284A, and about 1000A. The k-values respectively were 3.9, 140, 2400, and 1000 cm^{-1}. The k-values for the first two continua agreed fairly well with those of Romand and Mayence.[1] A number of diffuse bands were found superposed on some of these continua. For CO_2, three and possibly four absorption continua were observed. In the region 1440–1670A, the k-values for CO_2 were found considerably higher than those reported by Wilkinson and Johnston.[2] Superposed on these continua were numerous diffuse bands. Values of k as high as 4400 cm^{-1} were observed in the region below 1200A. At Lyman alpha our result agreed with the value of Preston.[3]

[1] J. Romand and J. Mayence, Compt. Rend. **228**, 998 (1949).
[2] P. G. Wilkinson and H. L. Johnston, J. Chem. Phys. **18**, 190 (1950).
[3] W. M. Preston, Phys. Rev. **57**, 887 (1940).

K11. The Vibrational Spectrum of Chlorotrifluoroethylene. D. E. MANN AND N. ACQUISTA, *National Bureau of Standards.*—The ideal gas entropy value for chlorotrifluoroethylene (CTFE) at its boiling point, 244.80°K, that is based on the vibrational assignment given by Smith *et al.*[1] is about 2.2 eu smaller than the value 73.28 eu obtained experimentally.[2,3] The infrared spectrum of CTFE has been reinvestigated in more detail and over a more extensive region, 4000 − 190 cm^{-1}, than in the earlier work.[1] Two hitherto unobserved bands have been found at 369 cm^{-1} and 194 cm^{-1}. The investigation under high dispersion of combination bands in the region 1900–2000 cm^{-1} has demonstrated the existence of two type C fundamentals at about 172 cm^{-1} and 163 cm^{-1}. These data, together with the previously available Raman data,[1] have made possible the achievement of a new and more satisfactory assignment: 1792(ν: CC), 1336(ν: CF), 1215(ν: CF), 1058(ν: CF), 689(ν: CCl), 538(δ: CF_2), 463(δ: CFCl), 338(ρ: CF_2), 194(ρ: CFCl) of species a', and 369(β: CF_2), 172(β: CFCl), 163(τ) of a''. The entropy value based on the present assignment is 73.79 eu.

[1] D. C. Smith et al., NRL Report 3567, Washington, D. C., September 15, 1949.
[2] Oliver, Grisard, and Cunningham, J. Am. Chem. Soc. **73**, 5719 (1951).
[3] Furukawa, McCoskey, and Reilly, J. Am. Chem. Soc. (to be published).

K12. Application of the Fermi-Thomas Model in Computing the Dipole Moment of Iodine Chloride.* HERBERT GLAZER AND HOWARD REISS, *Boston University.*—Using the Ritz variation method for N_2 Hund found the solution to the nonlinear Fermi-Thomas equation was closely approximated by a superposition of two spherically symmetric fields centered at each nucleus, respectively. The superposition of two spherically symmetric distributions of charge cannot produce a result having a dipole moment. Hund's solution might not be satisfactory for highly polar molecules. Also the small error in the total distribution which Hund states the superposition solution introduces may actually be large relative to the valence electrons alone in molecules where these electrons constitute only a small fraction of the total. It seemed advisable therefore to solve the equation for a heavy polar diatomic molecule having a moment whose value was known experimentally, i.e., ICl. The literature values average about 0.57 *D*. The equation was set up in finite difference form and solved on a desk calculator by the relaxation method of Southwell. The dipole moment was determined numerically from the relaxation net values after four relaxations to be 0.3 dyne.

* Supported by the AFCRC.

FRIDAY MORNING AT 10:00

Jefferson 250

(J. C. STREET presiding)

Invited Paper

L1. Fluctuations and the Latitude-Effect of Cosmic Rays at High Altitudes and Latitudes. H. V. NEHER, *California Institute of Technology.* (30 min.)

Cosmic Rays, I

L2. The Energy Distribution of Cosmic Rays.* H. V. NEHER AND E. A. STERN, *California Institute of Technology.*—When a histogram was plotted showing the amount of cosmic-ray energy being brought in by particles of a certain range of momentum, determined by the earth's magnetic field, a peak in the energy distribution was indicated at a few Bev/Zc.[1,2] Recent experiments at high altitudes and latitudes have shown a definite cutoff of primary cosmic rays at 58°±1° geomagnetic north. We assume that a solar magnetic field is responsible for the cutoff. Both theoretical and experimental evidence indicates that the cutoff is quite abrupt. Modification of the histogram at higher latitudes, given by one of us,[2] to take account of this cutoff now results in an energy distribution that need not pass through a maximum at great distances from the sun.

* Assisted by the joint program of the ONR and AEC.
[1] Bowen, Millikan, and Neher, Phys. Rev. **53**, 855 (1938).
[2] H. V. Neher, Phys. Rev. **83**, 649 (1951).

L3. East-West Asymmetry for Positive and Negative Mesons Near the Equator.* F. HARRIS, B. ROSSI, *M.I.T.*, AND I. ESCOBAR VALLEJO, *Universitad Mayor de San Andres, La Paz, Bolivia.*—We have measured the east–west asymmetry of positive and negative mesons at the Observatory of Chacaltaya, Bolivia, which is located at 5200-meters altitude and at approximately 16°S latitude. We used deflection in magnetized iron to select positive and negative mesons in two different momentum ranges, centered at about 0.8 and 1.8 Bev/*c*, respectively. Preliminary results obtained at a zenith angle of about 45° are summarized in Table I, where the asymmetry A is defined in the conventional way [i.e., $A=2\,(W-E)/(W+E)$].

TABLE I.

	Low momentum band	High momentum band
Positive mesons	$A=0.47\ \pm0.035$	$A=0.49\ \pm0.015$
Negative mesons	$A=0.084\pm0.037$	$A=0.119\pm0.016$

* Supported in part by the joint program of the ONR and AEC.

L4. Atmospheric Effects on Cosmic-Ray Intensity at Sea Level.* S. OLBERT, *Physics Department and Laboratory for Nuclear Science, M.I.T.*—The effect of the atmosphere on the vertical intensity of μ-mesons at sea level was studied theoretically. Sands'[1] expression for the production spectrum was used and the survival probabilities were computed rigorously. For the relative change in the vertical intensity $\delta i_v/i_v$, the following formula was obtained:

$$\delta i_v/i_v = a_H(R)\delta H(x_1)+a_K(R)\delta T_{av}(x_2)+a_P(R)\delta x_0,$$

where R is the residual range at sea level; $\delta H(x_1)$ represents the departure from the mean of the height of the pressure level $x_1(R)$; $\delta T_{av}(x_2)\equiv(x_0-x_2)^{-1}\int_{x_2}^{x_0}\delta T(x')dx'$ represents the departure from the mean of the temperature overhead, averaged between the pressure level $x_2(R)$ and the ground pressure x_0; and x_0 represents the departure from the mean of the ground pressure. Explicit formulas for $x_1(R)$ and $x_2(R)$, and for the coefficients aH, aK and aP are derived and evaluated numerically for $100<R<400$ g cm^{-2}. The values of $x_1(R)$ vary between 180 and 80 g cm^{-2}, while those of $x_2(R)$ vary between 340 and 120 g cm^{-2}. The results obtained appear to agree with the experimental observations, in so far as a comparison can be made.

* Supported in part by the joint program of the ONR and AEC.
[1] M. Sands, Phys. Rev. **77**, 180 (1950).

L5. High Energy Cosmic-Ray Interactions in Photographic Emulsion and Lead.* D. M. RITSON, M. F. KAPLON, AND W. D. WALKER, *University of Rochester.*—In a flight at White Sands in April, 1952, an arrangement consisting of a 750-cc "Block" of photographic emulsion on top of an "emulsion cloud chamber" was flown at 90 000 ft for several hours. The block consisted of 92 400μ G.5 stripped emulsions piled one above the other, and the emulsion cloud chamber contained twenty-five 3-mm lead plates separated by 250μ photographic plates. Six proton induced interactions and one secondary interaction with energies of the $\sim10^{13}$ ev have been observed in the emulsion with multiplicities of the $\sim$15 and N_h values of 0, 0, 2, 4, 6 and 15 (the secondary interaction had an N_h of 2). Thus, low N_h values are characteristic of high energy primary, as well as secondary, interactions in emulsion. The events found in lead ($\sim3\times10^{12}$ ev) show a strong increase in apparent multiplicity with increasing distance of the interaction back in the first lead plate setting a limit on the lifetime T of the π^0 meson, $T\leqslant10^{-14}$ sec. The multiplicity is similar to that observed previously for interactions in brass and for the inter-

actions observed in emulsion, indicating a very weak dependence of multiplicity in a nucleus on the number of nucleons struck by the primary.

* This research was supported by the Air Research and Development Command.

L6. On the Two-Particle Showers from Be. L. GRODZINS, G. DEL CASTILLO, AND W. Y. CHANG, *Purdue University.*—Several observers have recently reported narrow angle pairs of penetrating charged particles which seem difficult to interpret satisfactorily by known interactions. In the experiments done in 1950–1951, with a 12-inch diameter cloud chamber, we obtained, along with 3 and more charged particle showers, 45 two-charged-particle showers from 9.6 g/cm² Be placed within the chamber. It has been suggested that perhaps some of these two-particle showers are of similar character. A careful re-examination of our results indicates that while we cannot exclude such a possibility, probably most (if not all) of our two-charged-particle showers may be accompanied by at least one unseen neutral particle and that, as a consequence, they are compatible with the theory of shower production by nucleon-nucleon collision. This conclusion may be borne out by the energy and momentum considerations and by the fact that about 40 percent of the two-particle showers have both particles on the same side of the producing particles. When all possible knock-on electrons have been subtracted from the number of two-particle showers observed, then the ratio, 26 to 12, of the two-charged particle to the three-charged particle showers is also compatible, within statistical error, with the known processes of nucleon-nucleon collision.

L7. Structure and Composition of Air Shower Cores.* HAROLD L. KASNITZ AND KURT SITTE, *Syracuse University.*—An experiment was carried out at Echo Lake, Colorado (altitude 10 600 feet) to study the cores of large air showers. A cloud chamber containing eight ½-inch lead plates, together with a hodoscope of 102 counters, served as core analyzer, while various coincidences of six extension trays in distances from 2 to 20 m from the chamber were used to select showers of several density ranges. Three main sets of data can be derived from the experiment: (1) The density distribution of electrons near the shower core can be compared with the theoretical results. (2) Similarly, the age dependence of the structure function can be studied by comparing the results of the three density ranges. (3) The relative abundance of μ-mesons, N-particles, and electrons near the core can be obtained as a function of the shower energy. Preliminary results of the analysis of about 1500 showers will be presented. No clear evidence for a multiple core structure was found.

* Supported in part by the AEC.

L8. Experiments on Air Showers, Part I.* R. W. WILLIAMS, *M.I.T.*, AND W. E. HAZEN, *University of Michigan.*—An arrangement of five ionization chambers at Echo Lake, Colorado, was used to sample the particle density of large cosmic-ray air showers. Using a knowledge of the particle density at five points in a small (3×5 meter) area, one can locate within reasonable limits the air shower cores that strike in or near this area. A radial distribution function for the electrons must be assumed, but the data can be used to correct it if it is radically wrong. The Moliere function was assumed, and, as expected from previous work, was found to be in error at distances less than half a meter from the core; the observed distribution lacks the pronounced singularity of Moliere's calculation. The corrected distribution function was used in determining the location of each shower, and its total number of electrons. A cloud chamber of 0.2 m² effective area, containing one ½-inch and four 1-inch lead plates, was located near the center of the ionization-chamber array and was triggered by a coincidence of any two ionization chambers. The cloud chamber was used to obtain information on the direction and energy spectrum of showers whose position and true size were determined by the ionization chambers.

L9. Experiments on Air Showers, Part II.* W. E. HAZEN, *University of Michigan,* C. A. RANDALL, JR., *Ohio University,* AND R. W. WILLIAMS, *M.I.T.*—Cloud-chamber photographs, obtained under the conditions described in Part I, were analyzed for the relative frequency of electrons and photons with energy $>10^9$ ev as a function of distance from the shower axis. It was found that the spectrum is much softer than predicted on the assumption of only a few energetic initiating photons. In order to account for the observed size of the shower as well as the scarcity of high energy rays, it is necessary to assume either a very large number of separate showers well beyond their maxima or a central core due to medium energy showers with an additional large contribution by low energy showers beyond their maxima. The zenith-angle distributions have been obtained for three different shower sizes. As one goes from showers with total number of electrons between 1.2 and 4.9×10^5 (average 2.5×10^5) to showers with $N>10^6$ (average 2.6×10^6), the mean zenith angle increases from 15 up to 22 degrees and the rms angle from 17 up to 24 degrees. A model with a few initiating photons fits the results much better than a simplified nuclear cascade model with equipartition of energy.

* Supported in part by the joint program of the ONR and AEC.

L10. Z-Dependence of Cross Section and Energy in Cosmic-Ray Stars.* IAN BARBOUR, *Kalamazoo College.*—Analysis has been completed on cosmic-ray induced disintegrations in metal foils[1] sandwiched between face-to-face emulsions exposed at balloon altitudes. After removal of the foil and development, each pair of plates is reconstructed in its original orientation and scanned for stars originating in the metal, and then it is separated for re-examination under high magnification. Data have been obtained on each track from stars in Au, Pt, Sn, Cu, Ni, and Al. (1) Geometrical considerations allow calculation of the equivalent range of every star particle observed to stop in the emulsion. (2) Calculation of the probabilities of detecting star particles permits conversion of the observed size distributions to the real size distributions, whose variation with atomic number is studied. (3) Variation of total integral cross section with atomic number is approximately geometrical. (4) From grain counts on each track, the number of "gray" tracks (25–100 Mev) per star is obtained, and its variation with atomic number is compared with theory, such as the predictions of Goldberger-type calculations.[2]

* This work has been aided by a Cottrell Grant from the Research Corporation.

[1] I. Barbour, Phys. Rev. **82**, 280 (1951).
[2] M. Goldberger, Phys. Rev. **74**, 1269 (1948).

FRIDAY MORNING AT 10:00

Paine Hall

(ENRICO FERMI presiding)

Neutron Physics, II

M1. A Method for Absolute Neutron Source Calibration.* M. F. CROUCH AND D. E. DILLER, *Case Institute of Technology.*—Recent experiments indicate that neutrons produced by bombarding Be with Po alpha-particles are accompanied by γ-rays of 4.4 Mev only. Assuming a fraction $b(\sim1)$ of the neutrons are accompanied by a single photon, the neutron

emission rate **N** can be determined from the counting rates N, G, and $\gamma:n$ of detectors of the (thermalized) neutrons, γ-rays, and delayed coincidences $\mathbf{N}=NG(1-\exp(-T/\tau))/b(\gamma:n)$. ($T$ and τ are the coincidence "gate" length and thermal neutron mean life, both measurable with additional circuitry.) Other sources with similar spectra can be calibrated by relative N rate measurements. Using NaI(Tl) and B^{10} detectors, the calculated **N** for a $\sim$200 sec^{-1} source (assuming $b=1$) exceeded the "known" **N** (based on Argonne source 38) by 7 percent. Measurement of b is in progress.

* Supported by the AEC.

M2. A Pulsed Source of Fast Neutrons. J. E. DRAPER* AND B. D. MCDANIEL, *Cornell University.*—It has been found possible to utilize the natural time-bunching of an extracted beam of $\frac{1}{3}$ harmonic 100-kev deuterons from the 16-inch cyclotron to produce a pulsed source of 14 Mev T−D neutrons. The timing pulse denoting arrival of the beam pulse at the T³−Zr target was obtained by fast amplification of the beam current pulse. A delayed coincidence curve between this timing pulse and the neutron pulses in a stilbene scintillation crystal 13 cm from the target showed a full width of less than 10 millimicroseconds with the repetition rate of 8 megacycles. The delayed coincidences were followed through more than one *RF* period and the background between bursts was about $\frac{1}{4}$ percent for a neutron energy bias of 2.5 Mev and $\frac{3}{4}$ percent for a bias of 0.5 Mev. An accurate bias was set by a slow coincidence measurement of pulse height. The background was further reduced by elimination of phototube noise pulses. The time of flight of 14-Mev neutrons over a 60-cm path was measured. External deflection to decrease the repetition rate was tested. The possibility of inelastic scattering measurements by fast neutron time of flight was demonstrated.

* Now at Brookhaven National Laboratory.

M3. Measurements with 390-Mev Neutrons.* A. J. HARTZLER AND R. T. SIEGEL, *Carnegie Institute of Technology.*—The internal beam of protons accelerated to 425 Mev by the Carnegie cyclotron has been allowed to impinge upon a 1-cm thick Be target in order to produce a high energy neutron beam. After collimation of the neutrons, their energy spectrum has been obtained from a study of the ranges of recoil protons produced in a paraffin radiator. The proton detector was a two-crystal scintillation telescope, with varying amounts of absorber placed between the crystals for the range measurement. The observed spectrum has a sharp maximum at 385–390 Mev and falls to less than 10 percent of its peak value by 415 Mev, with a neutron flux of 2×10^4 (>300 Mev) at the exit port in the shielding. Comparison will be made with the neutron spectra obtained from other cyclotrons. The same detecting apparatus has also been used to measure the total neutron cross section of carbon in good geometry for a mean neutron energy of 390 Mev, with a resolution at half-maximum of about 30 Mev. The preliminary value obtained for the carbon cross section is (0.278±0.009) barn.

* Supported in part by the AEC.

M4. Total Cross Section of Helium for High Energy Neutrons.* PETER HILLMAN AND R. H. STAHL,† *Harvard University.*—The construction of high efficiency neutron counters and of a target for liquified gases at this Laboratory has made possible the measurement of the total cross section of helium for high energy neutrons. The counter and the beam monitor each consisted of a 5819 photomultiplier looking at seven cm of a terphenyl in xylene solution in a polished aluminum container. Operation at about the same gain insured similar response to beam variations. The helium container was a 70 cm long brass foil tube, attached to a three-liter liquid helium reservoir. The energy spread of the neutron beam of the Harvard synchrocyclotron[1] was reduced by hardening with three mean free paths of polyethylene, resulting in a spectrum peaked at 92 Mev, with a 25 Mev full-width at half-height. The effective energy of the measurement was determined by comparing cross sections of several other elements obtained under identical circumstances with accepted values taken with neutron counters of known energy sensitivity.[2] The preliminary result for helium is $\sigma_t=188\pm20$ mb at 84 ± 4 Mev.

* This work was supported by the joint program of the ONR and AEC.
† AEC Predoctoral Fellow.
[1] D. Bodansky and N. F. Ramsey, Phys. Rev. **82**, 831 (1951); K. Strauch and J. A. Hofmann, Phys. Rev. **86**, 563 (1952).
[2] "Neutron cross sections," AECU 2040 (1952); A. E. Taylor (private communication).

M5. Total Neutron Cross Sections of Chlorine and Carbon.* R. M. KIEHN, CLARK GOODMAN, AND K. F. HANSEN, *M.I.T.*—Only a few spot measurements of σ_t(Cl) have been made above 300 ev.[1] Using CCl_4 in good geometry, $Li^7(p, n)$ neutrons, and a pressurized propane counter, we have measured σ_t(Cl) by the transmission method from 0.4 to 1.0 Mev at 30-kev intervals and from 0.45 to 0.75 Mev at 2-kev intervals with 1-kev intervals for close resonances. Target thicknesses of 1–3 kev resulted in observed widths of $\gtrsim2-4$ kev for each resonance observed. Corrections for carbon were made by simultaneously measuring σ_t(C) using graphite. The correction for scattering-in was $\lesssim2$ percent except for the larger scattering resonances. Calibrations of proton resonance magnet control were obtained from $Li^7(p, n)$ threshold ($E_p=1.882$ Mev) and from the sharp resonance in σ_t(S) at $E_n=0.594$ Mev. Resonances in σ_t(Cl) were closely spaced, 20 to $\sim$40 kev with an over-all average of about 10 kev, in accord with the anticipated high level density expected for odd-odd compound nuclei. It is not possible to determine the spin of any of the levels from the shapes of the observed peaks or to specify which isotope ($Cl^{37}=0.246$ and $Cl^{35}=0.754$ abundance) is responsible for a given resonance peak.

* Work jointly supported by ONR and Bureau of Ships.
[1] H. Aoki, Proc. Phys. Math. Soc. Japan **21**, 232 (1939); Zinn, Seely, and Cohen, Phys. Rev. **56**, 260 (1939); R. Sherr, Phys. Rev. **68**, 240 (1945).

M6. Recent Developments in the Methods of Analysis of Slow Neutron Transmission Data in the Neighborhood of Nuclear Energy Levels. EDWARD MELKONIAN, *Columbia University.*—In published reports, methods have been given for obtaining σ_0 and Γ for a particular level when partially resolved transmission measurements on a thick ($n\sigma_0\gg1$) and a thin ($n\sigma_0\ll1$) sample are available. The areas above the transmission curves give $\sigma_0\Gamma^2$ and $\sigma_0\Gamma$, respectively. The methods under discussion are extensions of the previous methods, but the extreme limitations on sample thickness are no longer required. Specifically, the general relationship between σ_0 and Γ has been obtained for a measurement on a sample of arbitrary $n\sigma_0$. Measurements on two samples of sufficiently different thickness then give two different relations between σ_0 and Γ, from which σ_0 and Γ can be deduced. The usefulness of this method is limited by the accuracy of the area determination, which is frequently difficult to make, mostly because of the uncertainty of the contribution to the area of portions above the wings of the transmission curve. To get around this difficulty, the area above the transmission curve is measured only to a suitable distance from exact resonance. Under these conditions it is again possible to obtain a relationship between σ_0 and Γ based on this partial area. Measurements on two samples of different thickness again lead to σ_0 and Γ. Some applications will be discussed.

M7. Low Energy Neutron Resonance Cross Sections for Holmium, Erbium, Lutecium, and Thulium.* H. L. FOOTE, JR.,† V. L. SAILOR, AND H. H. LANDON, *Brookhaven National Laboratory.*—The neutron resonance cross sections for holmium, erbium, thulium, and lutecium[1] have been measured on the Brookhaven National Laboratory crystal spectrometer[2] over the energy range of 0.1 ev to 30 ev. Resonances have been

found in each element as follows: holmium—3.96 and 12.8 ev; erbium—0.5, 6.10, 9.55, 16.0, 21.2, and 27.5 ev; thulium—4.0, 15.0, 18.0 ev; lutecium—1.57, 2.62, 4.80, 5.30, 11.4, 14.4, and 24.0 ev. The measurements were made with Be and NaCl monochromating crystals. The 0.51-ev resonance in erbium has been previously reported.[3] This study indicates a high density of resonances in the rare earths. It would appear practical to use the resonances found in these elements for making quantitative analyses for their presence in other samples.

* Research performed under auspices of the USAEC.
† Doctorial candidate from University of Utah.
[1] These samples were kindly loaned for this study by Dr F. H. Spedding, Director, Ames Laboratory, Ames, Iowa.
[2] Landon, Sailor, and Foote, see following abstract, M8; also L. B. Borst and V. L. Sailor, Phys. Rev. **85**, 711 (1952).
[3] Bernstein, Borst, Stafford, Stephenson, and Dial, Phys. Rev. **87**, 487 (1952).

M8. Neutron Resonance Energy Measurements with the Brookhaven Crystal Spectrometer.* H. H. Landon, V. L. Sailor, and H. L. Foote, Jr.,† *Brookhaven National Laboratory.*—The Brookhaven crystal spectrometer[1] has been used to measure the energies of the lowest neutron resonances in several elements with the following results.

Iridium	$E_0 = 0.654 \pm 0.003$ ev
Rhodium	$E_0 = 1.260 \pm 0.004$ ev
Indium	$E_0 = 1.458 \pm 0.005$ ev
Rhenium	$E_0 = 2.16 \pm 0.01$ ev
Gold	$E_0 = 4.93 \pm 0.03$ ev
Silver	$E_0 = 5.235 \pm 0.035$ ev

The precision of the results will be discussed and comparison made with time of flight energy measurements. A beryllium crystal has been used as a monochromator and found to be particularly well suited for this type of instrument, extending its useful range to about 50 ev with good resolution. The characteristics of the crystal in regard to intensity of Bragg reflection, resolution, spectral distribution, higher order contamination, and background have been studied. The general operating characteristics of the spectrometer, along with the associated circuits for automatic operation, will be discussed.

* Research performed under the auspices of the USAEC.
† Doctorial candidate from University of Utah.
[1] L. B. Borst and V. L. Sailor, Phys. Rev. **85**, 711 (1952); Rev. Sci. Instr. (to be published).

M9. Neutron Resonance Measurements with the Brookhaven Fast Chopper. D. J. Hughes, F. G. P. Seidl, H. Palevsky, and J. S. Levin, *Brookhaven National Laboratory.**—The Brookhaven fast chopper,[1] which will allow measurements of neutron resonances with an ultimate resolution of 0.05μ sec/m has been in operation at self-speed (6000 rpm) for 6 months. The present resolution has been determined empirically by measurement of sharp resonances with a result of 0.1μ sec/m. The major contribution (in the low energy region now being investigated) to the resolution time is the flight time of the neutrons in the detector (a bank of BF_3 proportional counters). The apparatus is now equipped with automatic controls and full time unattended operation is in effect. The improvement in resolution made possible with the chopper is shown by the additional resonances found in the materials that have been examined, and in the increase in peak cross section of the resonances compared to reported results. The manner in which resonance parameters can be directly measured because of the high resolution will be described, as well as the potentialities for level density determinations.

* Work carried out under contract with the AEC.
[1] Seidl, Hughes, and Palevsky, Bull. Am. Phys. Soc. **27**, No. 5, 12 (1952).

M10. Neutron Resonances in Ag, Th, and Mn. J. S. Levin, W. Y. Kato, N. G. Sjostrand, and D. J. Hughes, *Brookhaven National Laboratory.**—Initial measurements made with the Brookhaven fast chopper have shown that the high resolution available revealed resonance structure more complicated than that already published, even at low energy where the structure was presumably well resolved. Because of this finding, the chopper is now being used mainly in the energy region from 10 to 200 ev. Above 200 ev the resonances in heavy elements merge even with the present 0.1μ sec/m resolution of the chopper. In silver there are at least 6 resonances between 10 and 100 ev, some of these representing resonances that previously had not been resolved. In thorium the number of resonances has also increased, for example, the resonance at 26 volts is now resolved into two resonances with a 1.5-ev spacing. In manganese the resonance at 300 volts is measured with a peak height much greater than previously reported and a third level has been found in addition to those at 300 and 2000 ev. The level spacings as determined with the present resolution are in good agreement with the statistical model, in contrast to the apparent scarcity of previously known levels.

* Work carried out under contract with the AEC.

Friday Morning at 10:00

Allston Burr, A

(J. C. Slater presiding)

Invited Paper

N1. Recent Advances in the Interpretation of Luminescence in Solids. P. D. Johnson, *General Electric Company.* (30 min.)

Luminescence and Photoconductivity

N2. Influence of Electric Fields on Luminescence. Sol Nudelman and Frank Matossi, *Naval Ordnance Laboratory.*—A ZnS:Cu phosphor was exposed to a constant, near ultraviolet source. On applying an audiofrequency electric field to the phosphor, a momentary illumination lasting from 3–5 periods was observed. This was followed by an extinguishing effect whose magnitude was dependent upon field strength and frequency. Leaving the field on, the light output recovered slowly to an amount less than that obtained without the field. Another momentary illumination was observed when the field was turned off. While the field was on, the light output rippled with twice the field frequency. An illumination of very short duration (about 10^{-4} sec) was observed at the moment of applying or removing a dc field. The quantitative details of these effects will be discussed with respect to dependence on field strength and frequency. Observations with other phosphors will be presented.

N3. On the Luminescence of Divalent Manganese in Solids. Clifford C. Klick and James H. Schulman, *Naval Research Laboratory.*—Under certain conditions measurements on the emission and absorption of luminescent centers allow the determination of the configurational coordinate curves for the ground and excited states of the centers. The method is used

as a first approximation in obtaining configurational coordinate curves for divalent manganese in zinc silicate. These curves offer an explanation of the asymmetry of the manganese emission. Comparison of the energy levels for the manganese ion in the solid and gaseous state leads to an identification of the various levels and to the suggestion that emission in the solid state corresponds to a $4_G \rightarrow 6_S$ transition.

N4. The Alpha-Particle Induced Phosphorescence of Silver Activated Sodium Chloride.* C. E. MANDEVILLE AND H. O. ALBRECHT, *Bartol Research Foundation.*—When crystals of NaCl-Ag are irradiated by nuclear particles, fluorescence and phosphorescence are observed in two bands[1,2] centered respectively at ~2500A and ~4000A. The decay of the short-wave band (2500A) has been measured in photosensitive Geiger counters, and that of the long-wave band (4000A) in RCA-5819 photomultiplier tubes. The combined decay of both bands has been noted in RCA-1P28 phototubes. The decay rates of both bands have been measured separately when the same crystal has been irradiated on successive occasions under identical conditions as well as when the phosphorescing material has been placed between Geiger counter and photomultiplier to record simultaneously the decay of the two bands. It has been found that the two bands decay with differing power laws. For example, on a log-log plot, the short-wave band has been observed to assume a slope of -2.48 while the long-wave band decayed with a slope of -1.83. Slopes having absolute values of more than 2 have been consistently encountered.

* Assisted by the joint program of the ONR and AEC.
[1] H. O. Albrecht and C. E. Mandeville, Rev. Sci. Instr. **22**, 855 (1951).
[2] Milton Furst and Hartmut Kallmann, Phys. Rev. **82**, 964 (1951).

N5. Dielectric Changes of Electroluminescent Phosphor during Illumination. SHEPARD ROBERTS, *General Electric Research Laboratory.*—The phosphor used in this investigation consisted of ZnS (80 percent), ZnSe (20 percent) with copper as an activator. An incandescent light was used for illumination, and it was determined by use of filters that wavelengths in the vicinity of 4000A were most effective in producing the observed effects. Phosphor powder was incorporated in a thin film of plasticized polyvinyl chloride. The dielectric constant of the film was measured at 1000 cps under various intensities of illumination and at different applied voltages. The dielectric constant of the phosphor particles was calculated by methods described elsewhere,[1] treating the particles as though homogeneous. The results of these experiments show a somewhat greater variation of dielectric constant in this material under illumination than has been observed in ZnS phosphors[2] at higher frequencies. This is accompanied by a change in conductivity, although the conductivity change is by no means predominant even at this low frequency. In addition, the dielectric changes are markedly dependent on the applied voltage, becoming greater as the voltage is reduced.

[1] S. Roberts, J. Opt. Soc. Am. (to be published).
[2] Gudden and Pohl, Z. Phys. **1**, 365 (1920); Garlick and Gibson, Proc. Roy. Soc. (London) **A188**, 485 (1947).

N6. Photoemission from Silver into AgCl, KBr, NaCl, and New Bands of Photosensitivity in AgCl.* M. A. GILLEO, *M.I.T.*—The work required to move an electron from silver into NaCl, KBr, and AgCl has been investigated photoelectrically (NaCl and KBr, *ca* 4.3 ev, AgCl, *ca* 1 ev). In AgCl seven new bands of photoconductive response were found of a half-width of *ca* 0.2 ev at 90°K; they are bleached by irradiation. The 4400, 5000, 5700, 6600, and 7500A bands increase in intensity with an increasing supply of electrons provided by photoelectric emission and behave analogously to the *F* bands of the alkali halides. The 4800 and 9200A bands are favored by a scarcity of electrons and may correspond to trapped holes. The intrinsic photoconductive response of AgCl and the absorption edge on which it occurs shift toward shorter wavelengths with decreasing temperature; simultaneously the edge steepens. The maximum of response which appears with decreasing wavelength may arise from a bimolecular recombination of charge carriers released by light.

* Sponsored by the ONR, the Army Signal Corps, and the Air Force.

N7. Photocurrent, Space Charge Build-Up and Field Emission in Alkali Halide Crystals.* A. VON HIPPEL, E. P. GROSS, J. G. JELATIS, AND M. GELLER, *M.I.T.*—Alkali halide crystals, additively colored by "*F*" centers, represent, in a first approximation, a transparent solid with frozen-in electrons which can be mobilized by light absorption. When moving towards the anode, these electrons leave a positive space charge behind, and an adjustable cathode fall results which can be steepened until electrons are released by field emission. The steady state and transient solutions for various types of space charge distributions have been calculated, measurements under a variety of experimental conditions have been made, and a new type of field-emission photocell has been realized.

* Sponsored by the ONR, the Army Signal Corps, and the Air Force.

N8. Polarization Capacitance Effects in Photoconductors and Semiconductors. J. ROSS MACDONALD.* *Argonne National Laboratory.*—Earlier work on the photocapacitative effect[1] showed that an increase of as much as 50 times in the low frequency capacitance of an *F*-centered alkali-halide single crystal with metallic electrodes could be obtained by strongly illuminating the crystal with light in its *F*-absorption band. Work in progress has made it clear that the effect is largely due to photoconducting electrons which are not free to leave the crystal at room temperature. This conclusion has been confirmed by the correspondence between experimental results and the predictions of a polarization theory which includes the effects of space charge and diffusion in a material with blocking electrodes. The theory applies to the case where neutral centers are dissociated, either thermally or by the absorption of light, into mobile charge carriers and immobile centers of opposite sign and holds whether recombination is present or not. The theory thus applies both to semiconductors and to photoconductors. The correspondence between theory and experiment will be discussed with particular regard to the dependence of polarization capacitance and conductance on frequency, concentration of neutral (*F*) centers, light intensity, and electrode spacing. In addition, experimental evidence of harmonic generation by the medium will be presented.

* On leave from Armour Research Foundation.
[1] J. R. Macdonald, Phys. Rev. **85**, 381 (1952).

N9. Conductivity Changes in KCl Produced by γ and n Irradiation. C. M. NELSON, R. L. SPROULL,* R. S. CASWELL,† *Oak Ridge National Laboratory.*—Apparatus has been constructed for measuring the ionic conductivity σ of KCl at temperatures between 25°C and 700°C. The σ of the crystals was measured before irradiation and the results agree with (and extend the range of) previous σ-measurements[1] in the extrinsic temperature range. The measurements of σ of irradiated crystals have been made in the range 25°C to 220°C. Gamma- and neutron irradiations were carried out using a Co^{60} source and the Oak Ridge graphite reactor. The effect of short γ-irradiation is to reduce σ, as originally discovered by J. A. Ghormley in agreement with an independent observation on diffusion during x-irradiation by R. J. Maurer and D. E. Mapother. This is presumably caused by reducing the number of effective $K+$ vacancies by trapping holes on them, as proposed by the workers cited. Longer irradiations and neutron irradiations enhance σ, presumably by creating $K+$ vacancies. The annealing-out of the changes has been studied. When annealing at temperatures near 200°C has proceeded for a few hours, σ appears to have its original (unirradiated) values.

* Now at Cornell University.
† Now at National Bureau of Standards.
[1] H. Kelting and H. Witt, Z. Physik **126**, 697 (1949).

FRIDAY MORNING AT 10:00

Geology Lecture Room

(V. F. WEISSKOPF presiding)

Theoretical Nuclear Physics

NA1. On the Poles of the S Matrix for Nuclear Reactions. MARCOS MOSHINSKY, *Universidad de Mexico e Instituto Nacional de la Investigación Científica.*—In the formalism proposed by Wigner[1] for the description of nuclear resonance reactions, the S matrix is a function of the derivative matrix R, whose components as functions of energy in the complex plane have been extensively analyzed.[2] It has been shown that for resonance scattering, when the S matrix reduces to a meromorphic function, the dependence of S on R excludes the poles of the S function from the upper part of the wave-number plane, outside of the imaginary axis.[3] For nuclear resonance reactions, the components of the S matrix are no longer meromorphic functions of the wave number, but become instead, algebraic functions, and the poles of the S matrix are then distributed on a Riemann surface. Defining the first sheet of the Riemann surface as that in which, for energies above the thresholds, the wave numbers for all alternatives are real and positive, we show that the dependence of S on R, combined with the properties of R, exclude the poles of the S matrix from the upper part of the first sheet outside of the imaginary axis. This restriction on the position of the poles of the S matrix, can also be derived from a dynamical description of resonance reactions in Fock space.[4]

[1] E. P. Wigner, Phys. Rev. **70**, 606 (1946).
[2] E. P. Wigner, Ann. Math. **53**, 36 (1951).
[3] W. Schützer and J. Tiomno, Phys. Rev. **83**, 249 (1951).
[4] M. Moshinsky, Phys. Rev. **81**, 347 (1951).

NA2. Theory of Nuclear Reactions Involving Polarized Deuterons.* W. LAKIN AND L. WOLFENSTEIN, *Carnegie Institute of Technology.*—The polarization state of a deuteron may be specified by giving the statistical expectation values of a "complete set" of spin operators.[1] This complete set consists of one scalar (unity), the three components of a pseudovector (the total spin), and the five components of an irreducible second-rank tensor. If the polarized deuteron is produced in a simple reaction such that the initial and final states define one momentum each, invariance conditions require the normal to the reaction plane to be the spin direction and also a principal axis of the second-rank tensor. The possible states of polarization of the deuterons produced in the reaction $p+p\rightarrow\pi^{+}+d$ have been calculated. Previous considerations[2] have been limited to the spin, but actually polarization effects associated with the second-rank tensor appear to be more prominent. Furthermore, considering detection by scattering from unpolarized protons, one finds that the tensor-type polarization has a considerable effect even in the Born approximation.

* Supported by ONR.
[1] L. Wolfenstein and J. Ashkin, Phys. Rev. **85**, 947 (1952); R. H. Dalitz, Proc. Phys. Soc. (London) **A65**, 175 (1952).
[2] K. Watson and C. Richman, Phys. Rev. **83**, 1256 (1951).

NA3. Polarizability of the Deuterons.* B. J. MALENKA, U. E. KRUSE, AND N. F. RAMSEY, *Harvard University.*—The polarizability of the deuteron in an external adiabatically applied electric field has been calculated by means of second-order perturbation theory. Parity considerations enable us to replace the term corresponding to the sum over intermediate states by the Green's function for the deuteron. A first approximation to the deuteron Green's function which corresponds to the free particle Green's function can be obtained by considering the integral equation relating the two Green's functions. The value of the polarizability thus obtained is used to calculate the expected deviation from the Coulomb scattering cross section in a region where the classical theory of scattering is approximately valid. A simple method of estimating this deviation in the backward direction has been developed. At other angles we have essentially followed the method of Hardmeier.[1]

* Supported by the joint program of the ONR and the AEC.
[1] W. Hardmeier, Physik. Z. **28**, 181 (1925).

NA4. Coulomb Effects in Deuteron Stripping.* N. AUSTERN AND S. T. BUTLER, *Cornell University.*—A method has been developed for including the Coulomb field into the calculation of deuteron stripping angular distributions. The method is identically that used in the non-Coulomb limit,[1] the wave functions of the incident and outgoing particles being now replaced, however, by the appropriate Coulomb functions. The wave function for the incident deuterons is obtained in adiabatic approximation, the motion of the center of gravity of the deuteron being represented by an ordinary Coulomb function, and the deuteron polarization added on by perturbation theory. In obtaining the angular distributions, the contribution from the center of gravity term has been accurately calculated, while that from the polarization, although only estimated approximately, appears in general to be small. It is hoped that the results of numerical calculations at present in progress can be presented.

* Supported in part by the ONR.
[1] S. T. Butler, Proc. Roy. Soc. (London) **A208**, 559 (1951).

NA5. A Variational Principle for Neutron-Proton Scattering with Tensor Forces. L. C. BIEDENHARN, *Yale University,** AND JOHN M. BLATT, *University of Illinois.*—The occurrence of the tensor force has the consequence that the states of the neutron-proton system with parity $\pi=(-1)^{J+1}$ and angular momentum J contain two channels, i.e., $l=J\pm1$. The scattering matrix for these states is a 2×2 unitary and symmetric matrix which involves therefore three real parameters. We may most conveiently take these parameters to be the phaseshifts $\delta_{J\alpha}$ and $\delta_{J\beta}$ of the two eigenstates of the scattering, while the third parameter ϵ_J is related to the "mixing" of the $l=J\pm1$ waves in these eigenstates.[1] Variational principles for the phaseshifts $\delta_{J\alpha}$ and $\delta_{J\beta}$, as well as for the phaseshift $\delta_{J\gamma}$ for the single channel $(\pi=(-1)^{J})$ states, have been given by Schwinger.[2] We shall complete this scheme by demonstrating a variational principle for the remaining parameter ϵ_J. Application of this result to low energy $n-p$ scattering will be discussed. In particular, the first two terms in the expansion of $\tan\epsilon_1$ in powers of k^2 will be obtained exactly in terms of the zero energy eigenstate solutions.

* Assisted by the joint program of the ONR and AEC.
[1] J. M. Blatt and L. C. Biedenharn, Phys. Rev. **86**, 399 (1952).
[2] J. Schwinger, unpublished lecture notes, Harvard University (1947).

NA6. The Extreme Single-Particle Model and Beta-Decay. HENRY BRYSK, *National Bureau of Standards.*—In the nuclear shell model, individual nucleons are assigned definite states. For the beta-decay of odd-A nuclei, we consider the further simplified picture in which the transforming nucleon interacts only with an effective static potential representing the remaining (paired) particles. For even-A, a yet more extreme schema views the two unpaired nucleons as noninteracting, $j-j$ coupled particles in a well. The matrix elements thus

obtained are, in terms of those for the odd-A case,

$$M_{\text{even}}^2 = (2J'+1)(2j_1+1)W^2(JLj_2j_1'; j'j_1)|M|_{\text{odd}}^2,$$

where W is a Racah coefficient, and J, L, j_1, j_2 are the total angular momenta of the nucleus, lepton field, transforming nucleon, and other unpaired nucleon, respectively, the prime referring to the final state. Aside from the superallowed transition, there is agreement in most, though not all, cases (sometimes reducing the straggling of ft values) for the tensor interaction (with slight evidence of the need in addition for a Fermi rule contribution).

NA7. Pseudoscalar Beta-Decay and RaE. M. RUDERMAN,* *Columbia University.*—The interpretation of the RaE beta-decay spectrum implies a mixture of tensor and pseudoscalar interactions.[1] The pseudoscalar matrix element for a nucleon in a potential small next to Mc^2 is of order recoil momentum/$2Mc$. To fit the RaE spectrum it has therefore been necessary to assume a very large Fermi constant[2] $G_P \sim 300 G_T$. Although the *average* potential of a nucleon is $\ll Mc^2$, an estimate of $\int \beta\gamma_5$ depends on the detailed nature of the nuclear force, in particular the off-diagonal matrix elements in the plane wave representation. $\int \beta\gamma_5$ is calculated for the transition of an extra core nucleon with a nuclear interaction due to pseudoscalar coupled pseudoscalar mesons. A canonical transformation exhibits the usual nonrelativistic potential. In this new representation the beta-decay matrix element is greatly altered. Exchange transitions in which two nucleons participate in the beta-decay predominate. $\int \beta\gamma_5$ is sufficiently large for $G_P \sim 1/3G_T$. No such large increase exists for gradient coupling.

* National Science Foundation Postdoctoral Fellow on leave from University of California, Berkeley, California.
[1] A. G. Petschek and R. E. Marshak, Phys. Rev. **85**, 698 (1952).
[2] Ahrens, Feenberg, and Primakoff, Phys. Rev. **87**, 663 (1952).

NA8. On the Theory of the Directional Distribution and the Polarization of Beta- and Gamma-Rays Emitted by Oriented Nuclei. H. A. TOLHOEK, *The Johns Hopkins University.**—If radioactive nuclei are oriented with the aid of very low temperatures, the radiations which are emitted will, in general, have a directional distribution which differs from spherical symmetry and will, in general, be polarized. These effects were studied for the beta- and gamma-radiations of nuclei.[1] In allowed beta-transitions polarization occurs, though the directional distribution remains spherically symmetric if the nuclei are oriented. In forbidden beta-transitions both effects may occur. For gamma-transitions polarization (transverse and circular) may occur as well as deviation from spherical symmetry of the directional distribution. The general formulas are most easily derived with the use of the Racah algebra. This method is also used in the derivation of formulas for the change in orientation of nuclei by a beta-transition which precedes a gamma-transition. Information of different kinds concerning nuclei can be obtained with the aid of these phenomena.

* On leave from the Institute for Theoretical Physics, The University, Utrecht, Netherlands.
[1] H. A. Tolhoek and S. R. deGroot, Physica **17**, 1, 17, 81 (1951); H. A. Tolhoek and J. A. M. Cox, Physica **18**, 357, 359 (1952); and several papers by the same authors in Physica (to be published).

NA9. Nuclear Double Gamma-Emission. S. A. MOSZKOWSKI, *Columbia University,* AND V. L. TELEGDI, *University of Chicago.*—Processes involving the simultaneous participation of two electric dipole ($E1$) quanta have been considered for atoms by M. G. Mayer. In view of the success of calculations based on the single particle model to explain nuclear lifetimes for ordinary γ-decay as well as the present experimental possibility of detecting weak transitions, we have reconsidered nuclear double gamma-decay. Transitions involving spin changes up to 4, i.e., involving up to two quadrupole quanta, where investigated, confining calculations to the case $L_1+L_2 = \Delta J$ (L_1, L_2 = multipole orders of the two photons). For EL_1-EL_2 transitions it can be shown, in general (for a single particle, including potentials depending linearly on momentum), that it is necessary to consider at least two virtual intermediate states. For $\Delta J > 2$, the possibility of reliable estimates is further restricted by the fact that the transition can go via intermediate states of differing spin and parity. For the double dipole case, however, which is perhaps of most interest experimentally, fair estimates are possible. "Branching ratios" for double electric dipole *vs* single $E2$ decay are found to lie between 0.001 and 0.2 percent, depending on the position of the intermediate states; the values for $E1-M1$ *vs* $M2$ are of similar order of magnitude. The directional correlation of the two simultaneous quanta is identical with the one for the corresponding cascade, if *both* quanta are $E1$ (or $M1$).

NA10. The Collective Model of the Nucleus. JOHN A. WHEELER, *Princeton University,* AND DAVID L. HILL, *Los Alamos Scientific Laboratory.*—An individual particle moving through the nuclear interior experiences at the nuclear surface a sharp change in potential, as a consequence of which a strong coupling is set up between the given particle and other nucleons. This coupling leads to the existence of collective modes of oscillation of the nucleus, in which the boundary undergoes displacements which are periodic in time (capillary oscillations). Starting from the idealization of perfect saturation of nuclear forces, one therefore arrives at a picture—the collective model of the nucleus—which unites many of the features of the independent particle picture and the liquid drop model. There is a close analogy with molecular physics. In the one case a given assignment of electrons to orbital states determines a characteristic potential energy curve or surface for the vibration of the diatomic or polyatomic molecule. In the other case the state of the nucleons fixes the potential energy as a function of the parameters which describe the collective oscillations. The Franck-Condon principle has important consequences for the mechanism of typical nuclear processes. The theory and some applications of the collective model are presented in a paper which is to be published.

NA11. The First Excited States of Even-Even Nuclei. KENNETH W. FORD, *Princeton University.*—The first excited states of even-even nuclei are known to be largely $2+$ and to exhibit remarkable regularities in energy as a function of N and Z, with sharp spikes in the energy surface at the double magic nuclei and sharp ridges along the magic numbers (G. S. Goldhaber). The collective model of the nucleus, as expressed in A. Bohr's strong coupling approximation, has been applied to even-even nuclei; it correctly predicts these qualitative features of the first excited energy surface, as well as the spin and parity of the ground and first excited states. Quantitatively, the first excited energy is sensitive to second-order corrections. After such corrections, the computed level spacing is smaller than the observed spacing. The theory predicts a correlation between intrinsic nuclear distortions and first excited energies. Deformations calculated from first excited energies show reasonable agreement with deformations calculated from quadrupole moments for the heavy nuclei, but are generally larger than the latter. Very large quadrupole moments are predicted for the region around uranium. A correlation between first excited energies and anomalies in isotope shifts also supports the idea that the nonspherical shape of the nucleus is important for the properties of even-even nuclei.

NA12. Contribution of Nuclear Distortion to Isotope Shifts. L. WILETS, *Princeton University,* D. HILL, *Vanderbilt University,** AND K. W. FORD, *Princeton University.*—Spectroscopic isotope shifts among the heavy elements have been generally attributed primarily to the nuclear volume effect. The contribution of nuclear distortions has been investigated, and it is found that for an ellipsoidal nucleus with uniform charge distribution the contribution of the distortion effect is

proportional to $(\delta(a_2^2)/\delta N)_z$, where a_2 is the fractional extension of the nuclear radius along the symmetry axis of the ellipsoid.[1] There is evidence from nuclear quadrupole moment and even-even energy level data that the contribution of nuclear distortion is of the same order of magnitude as the volume effect, and that it can describe quantitatively the regularities encountered in isotope shift anomalies. One must ascribe to the sum of all other effects a contribution half as great as the volume effect and in the opposite direction. Positive anomalies are predicted for $50<N<60$ and for $126<N<140$ where no analyzed isotope shift data is available. If distortions are greater for even-even nuclei than for odd nuclei, this could account in part for the even-odd staggering of isotope shifts.

* On leave at the Los Alamos Scientific Laboratory.
[1] Similar considerations have been applied to Sm and Nd by Brix and Kopfermann, Z. Physik **126**, 344, 431 (1949).

NA13. The *S*-Wave Two-Body Interaction in Nuclei.* DAVID H. FRISCH, *M.I.T.*—A cold Fermi gas of $A/2$ protons and $A/2$ neutrons is assumed to occupy a sphere of radius $R=r_0A^{1/3}$. Using unperturbed plane wave functions, the average potential is computed as the sum of two-body potentials acting between all pairs of particles. The two-body potentials are of mesic shape and are adjusted to give the observed $p-p$ singlet S-wave strength and range. The potential energy thus computed[1] will be given for various exchange dependences, and compared with the potential required from the computed kinetic and Coulomb energies and the observed binding energy. The virial coefficient $r_0\partial V/V\partial r_0$, which should equal $(2K+C)/V$ to give stability under the assumptions of this model, is also computed. The contribution of S-wave interactions is calculated separately to see whether S-waves alone give a sufficiently attractive potential and at the same time give stability at the observed radius. This interaction is feebly suggested by the possibility that the contributions of higher partial waves to the potential energy cancel out inside a nucleus. It is found to be intermediate between the $\boldsymbol{\sigma}_i\cdot\boldsymbol{\sigma}_j\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_j$ and $\frac{1}{4}+\frac{1}{4}P_{ij}$ interactions in its effects on the potential energy and on stability.

* Supported by joint program of the ONR and AEC.
[1] D. H. Frisch, Phys. Rev. **84**, 1169 (1951).

FRIDAY MORNING AT 10:00

Sanders Theatre

(OTTO OLDENBERG presiding)

Invited Papers

O1. Recent Results at High Pressures. P. W. BRIDGMAN, *Harvard University.* (30 min.)
O2. Echelle Spectroscopy. G. R. HARRISON, *M.I.T.* (30 min.)
O3. Experimental Discoveries Announced in the Programme of the Meeting of Fifty Years Ago. G. F. HULL, SR., *Dartmouth College.* (30 min.)
O4. Physical Studies on Viruses. E. C. POLLARD, *Yale University.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Sanders Theatre

Joint Ceremonial Session of the APS and the AAPT

(ENRICO FERMI presiding)

Retiring Presidential Address of the American Physical Society

P1. Two Barrier Phenomena. J. H. VAN VLECK, *Harvard University.*

(W. S. WEBB presiding)

Presentation of the Oersted Medal of the AAPT

P2. Response of the Oersted Medallist: The Heritage of a Physics Teacher. R. M. SUTTON, *Haverford College.*

Eleventh Richtmyer Memorial Lecture of the AAPT

P3. Nuclear Magnetism. E. M. PURCELL, *Harvard University.*

FRIDAY EVENING AT 7:00

Hotel Continental

(J. H. VAN VLECK AND W. S. WEBB presiding)

Banquet of the Society and the Association

After-dinner speech by J. A. STRATTON, *M.I.T.*

Presentation of the first Oliver E. Buckley Solid State Physics Prize to W. SHOCKLEY.

SATURDAY MORNING AT 9:30

Sanders Theatre

(J. B. JOHNSON presiding)

Business Meeting of the Division of Electron Physics

Symposium of the Division of Electron Physics

Q1. Electron Physics in the Upper Atmosphere. MARCUS O'DAY, *Air Force Cambridge Research Centre.* (30 min.)

Q2. Studies of Thermally Ionized Gases Produced by Shock Waves. ARTHUR KANTROWITZ, *Cornell University.* (30 min.)

Q3. Studies in Oxide-Coated Cathodes. L. S. NERGAARD, *RCA Laboratories.* (30 min.)

Q4. The Strong Focusing Synchrotron. M. S. LIVINGSTON, *M.I.T. and Brookhaven National Laboratory.* (30 min.)

SATURDAY MORNING AT 10:00

Fogg Museum

(BRUNO ROSSI presiding)

Cosmic Rays, II

R1. Neutrons Produced in Cosmic-Ray Stars. WILLIAM C. G. ORTEL,* *Yale University.*—An experiment has been performed at Climax, Colorado, at 11 200-ft altitude, to study the production of neutrons in cosmic-ray induced nuclear disintegrations. Those disintegrations occurring in a liquid scintillation counter (a solution of terphenyl and diphenylhexatriene in phenylcyclohexane) were selected. Fast neutrons from these disintegrations were detected by a set of BF_3-filled proportional counters arranged in a paraffin moderator surrounding the scintillator. Delayed coincidences between the scintillator and neutron counters were sought, and for each coincidence the size of the scintillation and the delay time of the neutron count were recorded. In several hundred cases two or more neutron counts came in delayed coincidence with a scintillation. Certain conclusions may be drawn from these data regarding the rates at which nuclear disintegrations of various ranges of energy occurred in the scintillator, and the multiplicities with which neutrons were produced in these disintegrations. Auxiliary data were taken to support these conclusions, and in particular to show the contribution of air showers to the coincidence rate.

* AEC Predoctoral Fellow.

R2. Scintillation Counter Measurements of the Absorption of the *N*-Component.* G. W. CLARK, *M.I.T.*—A double crystal scintillation counter has been constructed which responds selectively to low energy stars. The counter consists of two round crystal slabs of sodium iodide arranged one above the other so that cosmic radiation striking the lower crystal (*B*) must first traverse the upper crystal (*A*). Crystal *B* is a cylinder 1 cm high and 8 cm in diameter. A cosmic-ray event in the counter can be characterized by the sizes of the coincident scintillation pulses produced in *A* and *B*. The counters were calibrated with μ-mesons. Two pulse-height combinations have been studied in detail: (1) large *B* pulse, no *A* pulse; (2) large *B* pulse, small *A* pulse. Combinations (1) and (2) are produced primarily by stars in crystal *B* induced by neutrons (1) and by charged *N*-particles (2). Stars generated by photons closely accompanied by electrons are rejected by combination (1). Measurements with this detector reveal no increase greater than 5 percent in the rate of *n*-stars under a slab of lead 10 g cm^{-2} thick. The attenuation lengths of *n*-stars in lead, carbon, and air were found to be $\lambda_{Pb}=350\pm15$ g cm^{-2}; $\lambda_C=260\pm35$ g cm^{-2}; $\lambda_{air}=148\pm2$ g cm^{-2}.

* Supported in part by the joint program of the ONR and AEC.

R3. Experimental Results on Neutral V Particles.* C. PEYROU, R. SAFFORD, AND H. BRIDGE, *M.I.T.*—Among 22 000 photographs taken at 10 600 feet with a multiplate cloud chamber, 65 neutral *V* particles were found. There were 27 which originated in nuclear interactions inside the chamber. Of these, 22 were identified as decaying into two particles of unequal mass. These are referred to as V_1^0 particles. The experimental data are consistent with the assumption that the decay products are a proton and a pi-meson. The secondary tracks were nearly coplanar with the origin of the V_1^0 particle. The apparent deviations from coplanarity were easily explained by errors of measurement and were, in any case, too small for a three-body decay process. In 20 cases a range measurement was possible on one of the secondary particles. The energy release (*Q*-value) was then calculated on the basis of a two-body decay. These determinations are fairly accurate, the error being ±5 Mev in some cases. Results point to a unique *Q*-value of 38 ± 2 Mev. The mean life of V_1^0 particles turned out to be $(3\pm1)\times10^{-10}$ sec. The 5 *V*-events not clearly identified as having decay products of unequal mass (V_2^0-

events) are best explained by a two-body decay into two pi-mesons with a Q-value of 90–150 Mev. The V_2^0 tracks were coplanar with their origins.

* Supported in part by the joint program of the ONR and AEC.

R4. Cloud-Chamber Observations on the Unstable Heavy Charged Particles in Cosmic Rays.* R. SAFFORD, C. PEYROU, H. BRIDGE, AND B. ROSSI, *M.I.T.*—In a series of pictures taken with a multiplate cloud chamber at Echo Lake, Colorado, we found eight examples of charged particles heavier than π-mesons, which decay after coming to rest in the chamber (S particles), and 6 examples of charged heavy particles which decay in flight (charged V particles). It appears possible to explain the experimental results obtained under the assumption that all S particles and all charged V particles are of the same kind, and that their decay is a two-body process. In this case, the mean life of the particles lies between 10^{-9} and 10^{-8} sec. The charged decay product appears to be a π-meson of about 212 Mev/c momentum. The mass of the primary particles lies between 1000 electron masses and the proton mass. S particles and charged V particles may be of the same nature as the so-called χ-particles observed in photographic emulsions.

* Supported in part by the joint program of the ONR and AEC.

R5. Magnetic Field Cloud Chamber for Studying Nuclear Interactions in the Cosmic Radiation. I. Equipment.* J. BALLAM, D. R. HARRIS, A. L. HODSON, R. RONALD RAU, G. T. REYNOLDS, AND MARCELLO VIDALE.—A large cloud chamber having an illuminated region of 15 cm deep by 40 cm square has been constructed and placed in the gap of an electromagnet for the purpose of measuring momenta of cosmic-ray particles. The 10-ton magnet has 45-cm pole pieces and a gap of 23.4 cm. One pole is hollow for photographing the cloud chamber. An average field of 4500 gauss is produced in the gap by a power of 30 kw. It is possible to increase the power to 60 kw and obtain substantially higher fields. A copper plate 3.8 cm thick is placed across the center of the chamber and a copper wedge equivalent to a thickness of 6 cm forms the top of the chamber. A telescope is used for selecting penetrating showers and consists of one tray of Geiger tubes above and three trays of proportional counters, one on top of the other, below the chamber. The cloud chamber is triggered on a coincidence consisting of ≥ 1 Geiger tube plus an ionization pulse ≥ 3 times minimum ionization in each tray of proportional counters. The magnet, cloud chamber, and auxiliary equipment are mounted permanently in a large semi-trailer.

* Supported by the joint program of the ONR and AEC.

R6. Magnetic Field Cloud Chamber for Studying Nuclear Interactions in the Cosmic Radiation. II. Preliminary Results.* R. RONALD RAU, MARCELLO VIDALE, G. T. REYNOLDS, D. R. HARRIS, A. L. HODSON, AND J. BALLAM.—The equipment described in the previous abstract has been operated at the Inter-University High Altitude Laboratory located at Echo Lake, Colorado (altitude 10 600 feet), for approximately four months. A preliminary analysis of 1000 photographs indicates the following rates: (a) 10 pictures per hour of sensitive time; (b) 2–3 penetrating showers per hour of sensitive time; (c) 1–1.5 V^0 particles per day.

* Supported by the joint program of the ONR and AEC.

R7. Families of Fundamental Particles. M. GOLDHABER, *Brookhaven National Laboratory.**—If one tentatively identifies one of the observed types of neutral "V particles" as a member of the χ-meson family, χ^0, one finds that many of the results[1,2] on heavy mesons obtained at Bristol, Manchester, Pasadena, and elsewhere are compatible with the genetic relations given in the following table.

Particle	Mass (m_e)	Main modes of decay
$\chi^\pm$	1480 ± 100	$\pi^0+\pi^{\pm,0}$
χ^0	~ 1370	$\pi^\pm+\pi^\mp$
$\tau^\pm$	977 ± 5	$\pi^\pm+\pi^++\pi^-$
τ^0	900 ± 100	$\pi^0+\pi^++\pi^-$
V^0	~ 2200	$p+\pi^-(+\nu?)$

The χ-mesons are apparently produced directly in nuclear collisions[1] and may play a role in determining nuclear forces at small distances $d \sim \hbar/m_\chi c \sim 2.5 \times 10^{-14}$ cm. The V^0 decay shows the asymmetry common to processes in which nucleons are involved. Arguments for and against the existence of anti-nucleons are restated.

* Under the auspices of the AEC.

[1] Report on Copenhagen Conference, June, 1952.
[2] Leighton, Wanlass, and Anderson, Phys. Rev. (to be published).

R8. A New Magnet Chamber for the Study of V Particles.* A. V. BUSKIRK, H. O. COHN, L. R. ETTER, C. J. KARZMARK, R. H. REDIKER, AND R. W. THOMPSON, *Indiana University.*—A new magnet cloud chamber has been constructed and is being used in a sea-level experiment on the disintegration of V particles. The cloud chamber is of the type in which a rubber diaphragm moves between rigid stops, the illuminated volume being 11 in. wide, 22 in. high, and 5 in. deep. At a power of 40 kw, the iron electromagnet produces a field of 7000 gauss with an extreme variation of ± 5 percent over the illuminated volume. The expansion of the chamber is achieved by release of compressed air through two 6-in. holes in the back pole. Three stereoscopic photographs are taken at angles of $-10.6°$, $0°$, and $+10.6°$ with respect to the axis of the chamber through a wedge-shaped hole in the front pole. The three camera lenses of 75-mm focal length photograph the chamber directly at a mean magnification of 0.113. The chamber is actuated by an array of counters which requires 1 penetrating particle above the chamber and 2 below. The experiment is in progress and results concerning the V particle disintegration schemes will be presented.

* Assisted by a grant from the Frederick Gardner Cottrell Fund of the Research Corporation and by the Office of Army Ordnance Research.

SATURDAY MORNING AT 10:00

Allston Burr, A

(MARTIN DEUTSCH presiding)

Invited Paper

S1. Establishment of an Absolute Energy Scale in Beta-Spectroscopy. GUNNAR LINDSTROM, *Nobel Institute of Physics, Stockholm.* (30 min.)

Radioactive Nuclei, I

S2. Inner Bremsstrahlung and Ionization of the Atom Accompanying β-Decay. F. BOEHM AND C. S. WU, *Columbia University.*—Among the various secondary effects accompanying the process of β-decay, the inner bremsstrahlung caused by the acceleration of the β-particles in the field of its own nucleus and the ionization of the atomic core as the β-particle leaving

the atom have been investigated with both the scintillation and the proportional counter spectrometers. The radioactive sources used were carrier free RaE^{210}, Pm^{147}, and S^{35}. The energy spectra of the inner bremsstrahlung are in good agreement with the theoretical predictions. The K_α, K_β and L_α, L_β characteristic radiations of Po, Sm have been observed and identified from RaE^{210} and Pm^{147} as the results of β-decay. Because of the high background resulting from inner bremsstrahlung, one could only estimate the order of magnitude of the ionization yields and they are compared favorably with Migdal's predictions. In the case of S^{35}, a pronounced line at 2.6 kev was also observed. However, a portion of the line may be due to the fluorescence radiations from a trace of chlorine and sulphur in the source.

S3. Measurement of Gamma-Ray Spectra Using a Three-Crystal Pair Spectrometer. H. I. West and L. G. Mann, *Stanford University.*—A three-crystal [NaI(Tl)] pair spectrometer has been built, and its performance has been studied for γ-ray energies up to 5 Mev. $1\frac{1}{2}$ in. $\times$ $1\frac{1}{2}$ in. cylindrical side crystals are used to detect pair events in the center crystal ($\frac{1}{2}$ in.$\times\frac{3}{4}$ in.$\times 1\frac{1}{2}$ in.). Background pulses which are not due to pair events are virtually eliminated through the use of a 6-in.$\times\frac{1}{4}$-in. diam lead collimator and differential pulse-height discrimination on both side crystals. Under these conditions source strengths of $\sim$0.01 to 1 mc are needed, and $\sim$1 percent of the pairs formed in the center crystal are detected. A background of reduced energy pulses is associated with each γ-ray. This is due to escape of bremsstrahlung and of electrons from the center crystal, and due to degraded radiation which penetrates the lead collimator. Calculations and measurements of these effects will be discussed for γ-rays up to 5 Mev. Line shapes obtained from Co^{60}(1.17 and 1.33 Mev), Na^{24}(1.38 and 2.76 Mev), and Ga^{66}(10 γ-rays in the region 1.9–5 Mev) will be shown. Circuits will be discussed briefly.

S4. Beta-Gamma Polarization Correlations.* Donald R. Hamilton, *Institute for Advanced Study and Princeton University,* and Aaron Lemonick and Francis M. Pipkin. *Princeton University.*—Measurements have been made of beta-gamma polarization correlation[1] for several nuclei (As^{76}, Sb^{124}, K^{42}, Rb^{86})[2] already known to exhibit beta-gamma directional correlation. Gammas emitted at 90° to a beta are counted if scattered from one to the other of a pair of stilbene crystals ("analyzer"); triple coincidences (beta-gamma-gamma) are observed as a function of analyzer rotation. As a preliminary measurement the polarizations of Co^{60} and Cs^{137} gammas were observed when Compton-scattered at 90° from a stilbene crystal which replaced the beta-crystal; anisotropies of 34 and 49 percent, respectively, and expected sign were observed. In combination with known beta-gamma directional correlation results the sign of the anisotropy in the beta-gamma polarization correlation measures the parity change in the gamma emission. For As^{76} and Sb^{124} the results indicate no parity change (electric quadrupole or magnetic dipole); results on K^{42} and Rb^{86}, for which data in hand has not been completely analyzed at this writing, will also be reported.

* Supported in part by the AEC and Higgins Scientific Trust Fund.
[1] R. Stump, Phys. Rev. **86**, 249 (1952).
[2] Source materials supplied by Oak Ridge, Brookhaven, and Chalk River.

S5. Beta-Recoil Correlation in the Decay of He^6.* Brice M. Rustad and Stanley L. Ruby, *Columbia University,* and *Bookhaven National Laboratory.*—The angular correlation between the electron and the recoil nucleus in the decay of He^6 has been examined over the range from 90 degrees to 180 degrees for several electron energies. The direction and energy of the electron are determined by a stilbene scintillation spectrometer pivoting about a small gaseous source volume. The recoil ions, after being collimated by a differential pumping diaphragm, are detected by an Allen-type multiplier. The diaphragm is one of the elements of a pumping system which defines the gaseous source. Since He^6 has an allowed spectrum[1] with $\Delta I=1$, which means that it obeys $G-T$ selection rules, the experimental data will be compared with curves calculated with the tensor and axial vector interactions. The results favor the tensor interaction. Further experiments are in progress.

* Research carried out under contract with the AEC.
[1] Wu, Rustad, Perez-Mendez, Lidofsky, Phys. Rev. **87**, 1140 (1952).

S6. Proton-Gamma Angular Correlations in the $C^{12}(\hat{p},\hat{p}'\gamma)$ Reaction.* H. E. Gove,† *M.I.T.*—Angular correlations between the inelastic protons and the 4.45-Mev gamma-rays resulting from bombardment of C^{12} by 7-Mev protons have been studied. The protons were accelerated in the M.I.T. cyclotron and NaI(Tl) crystals with RCA 5819 photomultipliers were used as detectors. In one experiment the proton and gamma-counter were fixed 180° apart and the assembly rotated in a plane containing the incident beam. The resulting correlation can be described by the single angle θ between the proton beam and the inelastic protons. The number of proton-gamma coincidences per recorded proton has the form $1-(0.4\pm0.3)P_2(\cos\theta)$. In a second experiment the gamma-counter was fixed at 270° and the proton counter rotated from 30° to 150° to the beam (protons, gamma-rays, and beam coplanar). The results are similar to the same experiment using Mg^{24}.[1] The correlation results will be compared to the angular distributions of the protons[2] and the gamma-rays.[3]

* This work was assisted in part by the joint program of the ONR and AEC.
† Now at Atomic Energy of Canada Limited, Chalk River, Ontario.
[1] H. E. Gove and A. Hedgran, Phys. Rev. **86**, 574 (1952).
[2] H. E. Gove and H. F. Stoddart, Phys. Rev. **86**, 572 (1952).
[3] H. E. Gove and N. S. Wall (to be published in Can. J. Phys.).

S7. Internal Conversion in Na^{22} and Fe^{59}. G. Hinman, D. Brower, and R. Leamer, *Carnegie Institute of Technology.*—Measurements have been taken of the internal conversion coefficients of the 1.28-Mev gamma-ray in Na^{22} and the 1.10 and 1.30-Mev gamma-rays in Fe^{59}. For Na^{22} we find $\alpha_k=(6.3\pm2)\times10^{-6}$ which indicates that the transition is probably $E2$. For the 1.10-Mev gamma-ray of Fe^{59} we find $\alpha_k=(1.63\pm0.24)\times10^{-4}$ which indicates the transition is $E2$ or a mixture of $E2$ and $M1$. For the 1.30-Mev gamma-ray, $\alpha_k=(0.94\pm0.14)\times10^{-4}$ which indicates the transition is $M1$. In finding the conversion coefficients, the quantity measured in each case was α_t. We assumed $\alpha_k=\alpha_t(1.00/1.13)$ to take account of conversion in other shells. We were able to measure the ratio of the number of conversion electrons from the 1.10-Mev transition to the number from the 1.30-Mev transition more accurately than the absolute values of the coefficients. Our value for that ratio is $(N_e-(1.10)/N_e-(1.30))=1.91\pm0.09$. The results for Fe^{59} are in fairly good agreement with recent results of Metzger.[1]

[1] F. R. Metzger (private communication).

S8. Gamma-Rays from Mg^{26}.* John E. May† and Bruce P. Foster, *Yale University.*—The gamma-rays associated with the decay of the excited states of Mg^{26} have been identified by incorporating in a proton gamma-ray coincidence study the measurement of gamma-ray energies by a NaI(Tl) scintillation spectrometer. The coincidence pulses trigger a synchroscope on which the gamma-ray pulse heights are displayed for photographing on continuously moving film. The results of the coincidence study cast considerable doubt on the existence of the previously reported 0.44-Mev excited state. For the decay of the 1.83-Mev state, a single transition to the ground state was identified. Decay of the 2.97-Mev excited state was found to consist of competition between a strong 1.14-Mev transition to the 1.83-Mev state and a weak 2.97-Mev transition to the

ground state with an intensity ratio of about six. The decay of the 3.97-Mev state was found to occur by a 2.14-Mev transition to the 1.83-Mev state and probably by a much weaker 3.97-Mev transition direct to the ground state. For the decay of the 4.35-Mev state a 1.38-Mev transition to the 2.97-Mev state was established.

* Assisted by the joint program of the ONR and AEC.
† Now at Bell Telephone Laboratories, Murray Hill, New Jersey.

S9. The Decay Scheme of P^{29}. H. RODERICK, O. LÖNSJÖ, AND W. E. MEYERHOF, *Stanford University.*—The radioactivity from the reaction $Si^{28}(d, n)P^{29}$ produced by 2.8-Mev deuterons has been studied using two NaI(Tl) scintillation spectrometers in coincidence. The half-life has been found to be 4.45 ± 0.05 sec, using least squares analysis, in agreement with White.[1] Gamma-rays in coincidence with annihilation radiation have been found, indicating positron decay to the excited levels of Si^{29} at 1.28 and 2.43 Mev.[2] The branching ratios are 2.5 percent and 0.5 percent, respectively, giving log ft values of 4.3 and 3.8 assuming a ground-state positron energy of 3.63 Mev (log ft = 3.6).[1] The 2.04-Mev level in Si^{29} and cascade transitions between levels were not observed. To study these levels further, Al^{29} was produced and gamma-rays of 2.43 Mev (15 percent) and 1.28 Mev (85 percent) were found in agreement with the work of Seidlitz.[3] A 2.04-Mev gamma-ray, if produced, should be present to not more than 4 percent. Techniques of measurement, and possible spin and parity assignments of the excited states will be discussed.

[1] White, Creutz, Delsasso, and Wilson, Phys. Rev. **59**, 63 (1941).
[2] D. M. Van Patter and W. W. Buechner, Phys. Rev. **87**, 51 (1952).
[3] Seidlitz, Bleuler, and Tendam, Phys. Rev. **76**, 861 (1949).

S10. A Liquid Argon Ionization Chamber Measurement of the Shape of the Beta-Ray Spectrum of K^{40}.* JOHN H. MARSHALL,† *M.I.T.*—The beta-spectrum of K^{40} has been measured by observing the pulse-height distribution produced by stopping the beta-rays in an ionization chamber filled with liquid argon. A 0.4 mg/cm² source of 110-fold enriched KCl was deposited on a 1.6 mg/cm² aluminum foil by vacuum evaporation from the melt. The foil forming a cylinder 2 cm in diameter and 12 cm long was used as the cathode of a cylindrical chamber. With a collecting voltage of 22.5 kilovolts pulses due to electron collection following beta-ray ionization in the liquid argon were observed at the center rod anode. An anticoincidence system was used to avoid counting betas that backscattered through the foil. The results for K^{40} alone give an allowed Fermi plot above 800 kev. When a quantitative correction using the spectra of P^{32} and Y^{91} is made, the beta-spectrum of K^{40} agrees with the spectrum predicted by Marshak[1] for a third-forbidden transition with parity change.

* Supported in part by the joint program of the ONR-AEC. The KCl was supplied by the Isotopes Division, Oak Ridge National Laboratory.
† National Research Council Predoctoral Fellow 1950–1952.
[1] R. E. Marshak Phys. Rev. **70**, 980 (1946).

S11. On the Lifetimes of Excited States of Ni^{60}.* Z. BAY, V. P. HENRI, AND F. MCLERNON, *George Washington University.*—Using the 0.32 Mev β's of Co^{60} and the two subsequent γ's of Ni^{60}, a composite asymmetric $\beta - \gamma_1$, γ_2 delayed coincidence curve and a symmetric $\gamma_1 - \gamma_2$ delay curve have been measured. The application of moment theorems to the first and second moments of the two curves gives the lifetimes of the two isomeric states of Ni^{60} without need for a separate "prompt" source. In order to obtain narrower delay curves, we add to attenuated plate pulses of the photomultiplier delayed pulses of opposite polarity and twice the amplitude, originating from the last dynode. The resulting pulses will be isosceles triangles, the base lengths of which are independent of the initial pulse amplitudes. Using diphenyl acetylene scintillators we can diminish by this method the uncertainty of the time definition of our pulses, as they appear in the coincidence circuit, to 2×10^{-10} sec. This corresponds to the best theoretical predictions made by others. Preliminary measurements indicate that the two lifetimes of Ni^{60} do not exceed 10^{-10} sec.

* This work supported by the joint program of the ONR and AEC.

S12. Accuracy of Time Measurements by Delayed Coincidences.* H. KANNER, Z. BAY, AND V. P. HENRI, *George Washington University.*—It has been shown earlier[1] that the mean life, Θ, of a short-lived substance can be determined by a comparison of the moments of the delayed coincidence curves for the source in question and a source of "simultaneous" events. The standard deviation of the measured Θ can be derived from the moments of the normalized delay curves and the total number of coincidences observed. Calculations show that for a simple parent-daughter decay 10 000 counts will permit detection of a decay time 1/100 of the width of the delay curve in an asymmetric (e.g., β, γ) experiment, and $\frac{1}{10}$ of this width in a symmetric (e.g., γ, γ) one. For a Gaussian "prompt" coincidence curve, explicit formulas have been derived expressing σ/Θ as functions of the total number of counts and the quantity τ'/Θ, where σ is the standard deviation of Θ, and τ' is a resolving time[2] approximately given by the half-width of the "prompt" curve.

* This work was supported by the joint program of the ONR and AEC.
[1] Z. Bay, Phys. Rev. **77**, 419 (1950).
[2] Z. Bay, Phys. Rev. **87**, 194 (1952).

SATURDAY MORNING AT 10:00

Pierce Hall, 110

(W. H. FURRY presiding)

High Energy Scattering and Other Topics in Theoretical Physics

SA1. Exact Interaction of Scalar and Electrostatic Fields. ROBERT L. PEASE AND JANE S. PEASE, *RAND Corporation.*—The nonlinear equations of interacting scalar and electromagnetic fields are treated in the spherically symmetric, static case, with a singularity in the scalar field admitted at the origin. Approximate solutions are found by iterative, variational, and numerical methods under the postulates that (A) the total energy of a scalar particle in interaction with its own electrostatic field is mc^2, and (B) the total charge of the system is e. A spinless, static, spherically symmetric model of the proton is suggested. Setting m equal to the mass of the proton yields the following very approximate physical results: (1) The radius of the system is of the order of 3×10^{-13} cm, (2) the nonsingular portion of the field energy is of the order of 1 Mev, and (3) the departure from punctiformity of the resulting (protonic) charge distribution contributes of the order of 1 Mc/sec to the Lamb shift in hydrogen.

SA2. Tensor Operators in Isotopic Spin Space.* L. WOLFENSTEIN, *Carnegie Institute of Technology.*—Watson[1] and others have discussed the consequences of charge independence on pion production in nuclear collisions. To treat this problem we

consider operators which transform like the components T_{JM} of an irreducible tensor under rotations in isotopic spin space. Charge independence requires that the average value of such an operator in the final state must be a linear combination of the average values of an operator with the same J and M in the initial state. The operator $K(=a_1^*a_1+a_2^*a_2-2a_3^*a_3$, where a^* and a are pion creation and annihilation operators, respectively) transforms like T_{20}. In a collision of a nucleon with a target of isotopic spin zero, therefore, the final average value of K is zero: the number of charged mesons equals twice the number of neutral mesons, as has been previously deduced. Similarly it may be shown that in the collision of two protons the average value of K must lie between limits equal to minus one-half times the extreme values formally possible for K. It follows that in this case on the average at least half the pions produced must be charged.

* Supported in part by the OOR.
[1] K. M. Watson, Phys. Rev. **85**, 852 (1952).

SA3. Inner Bremsstrahlung in μ-Decay. A. Lenard, *State University of Iowa.*—The transition probability for the decay of a μ-meson resulting in the simultaneous ejection of an electron and a photon has been computed from second-order perturbation theory. The dependence on the energies of the two outcoming particles as well as on the angle between their direction of emission will be presented. The high energy end of the photon spectrum at a fixed angle relative to the electron is sensitive to the coupling type. Detection of the effect would require large μ-meson densities in the radiator.

SA4. Theoretical Analysis of Meson-Proton Scattering (I).* F. J. Dyson, S. S. Schweber, and W. M. Visscher, *Cornell University.*—The non-adiabatic perturbation theory of Lévy[1] has been applied to the analysis of meson-proton scattering, using charge symmetric pseudoscalar meson theory with a pseudo-scalar meson-nucleon interaction. Nuclear recoil and pair-creation are taken into account correctly. The wave function is represented as a combination of the configurations (1, 1), (1, 0), (3, 0), (1, 2), and (3, 2), where (m, n) denotes a configuration of m nucleons and n mesons. Our approximation lies in neglecting the effects of (3, 1) and of all configurations containing more than two mesons or three nucleons. Only to this extent do we assume weak coupling. We derive an integral equation for the (1, 1) component of the wave function alone, using the formalism of Goldberger[2] to describe the scattering process. No expansions in powers of the coupling constant are carried out in the derivation of this equation and the equation leads to scattering phase shifts radically different from those obtained by means of conventional perturbation theory. A similar, but approximate, integral equation has been derived previously by Chew (in print).

* Supported in part by NSF.
[1] M. Lévy, Phys. Rev. **88**, 72 (1952).
[2] M. L. Goldberger, Phys. Rev. **84**, 929 (1951).

SA5. Theoretical Analysis of Meson-Proton Scattering (II).* M. K. Sundaresan, E. E. Salpeter, and M. Ross, *Cornell University.*—The integral equation described above[1] is separated exactly into states of given total angular momentum J, total isotopic spin I, and parity. In the center-of-mass system in momentum space, one obtains an integral equation in one variable only, the momentum of the meson, the form of the equation depending on the particular state and on the energy. The value of the wave function on the energy shell determines the phase shift. The integral equation can be solved numerically or by means of an iteration method. For the $P_{\frac{1}{2}}$, $I=\frac{3}{2}$ state the phase shifts have the sign corresponding to an attractive potential and the phase shifts obtained are appreciably larger than those given by Born approximation; for the other S and P states, they have the opposite sign and are smaller than the Born approximation values. Preliminary estimates give rough qualitative agreement with experimental values,[2] except that the energy dependences of the S phase shifts are different. Numerical results will be given.

* Work supported in part by the ONR.
[1] See SA4, preceding abstract.
[2] Anderson, Fermi, Long, Martin, and Nagle, Phys. Rev. **85**, 934 (1952).

SA6. Asymptotic Behavior and Differential Equation of Meson Wave Function. H. A. Bethe and F. J. Dyson, *Cornell University.*—The integral equation for the one-meson wave function described in the preceding abstract has been solved for large meson momentum k. The wave function behaves as a power of k, $\psi\sim k^{-\frac{1}{2}-n}$, where n is determined by the coupling constant. Using the same approximate kernel as in the numerical solution of the last abstract, $n=\frac{1}{2}(1+G^2/8\pi^2)^{\frac{1}{2}}$ for the S state and $n=\frac{1}{2}(1-G^2/24\pi^2)^{\frac{1}{2}}$ for the $P_{\frac{3}{2}}$ state of $I=\frac{3}{2}$. In the (repulsive) S state, the wave function falls more sharply with increasing coupling constant, in the (attractive) P state less sharply. If n becomes zero or imaginary, the wave function ceases to be normalizable. This sets an upper limit to $G^2/4\pi$ which is 18.6. With the exact kernel, this limit is 26.9. With some approximation in the kernel, the integral equation can be transformed into a second-order differential equation. This can be solved, starting from large k with a well-behaved ψ. Resonance (phase shift 90°) will occur approximately for that G which makes $\psi=0$ at $k=0$; this is about $G^2/4\pi=15$ for the approximate kernel. The (approximate) dependence of phase shift on the energy of the incident meson is studied with the differential equation.

SA7. Evidence for Direct Meson-Meson Interaction. A. N. Mitra and F. J. Dyson, *Cornell University.*—Marshak (unpublished) has observed that the experimental phase shifts for the S-state with isotopic spin $I=\frac{3}{2}$ require a combination of repulsive short-range (order of nucleon Compton wave length) with attractive long-range (meson Compton wave length) interaction. Our calculations confirm that no long-range forces are predicted by meson theory except as the result of a direct meson-meson interaction, thus giving a possibility of obtaining this interaction from the experiments.[1] We have calculated the meson-meson interaction resulting from virtual production of nucleon pairs, separately for each state of given total isotopic spin and relative angular momentum. Neglecting all D and higher states, only the S-states for $I=0$, 2 and the P-state for $I=1$ are needed. The interaction is strong and attractive in the states $I=0$, 1. We are calculating the effect of this interaction in the integral equation for proton-meson scattering.[2] According to Brueckner (unpublished), the nucleon-meson and meson-meson interactions will not be even approximately additive.

[1] K. A. Brueckner and K. M. Watson, Phys. Rev. **87**, 621 (1952).
[2] See SA4, SA5, and SA6, preceding abstracts.

SA8. Radiative Corrections to Forward Compton Scattering. John S. Toll, *Princeton University.*—Radiative corrections of order e^6 to the Compton scattering cross section have been computed by Schafroth[1] and by Brown and Feynman.[2] In view of the disagreement between these authors, it is interesting to compute the forward Compton scattering, which can be simply calculated by direct application of the dispersion relation for light. An analysis of the logical foundations of the dispersion relation[3] has shown that the validity of the relation is equivalent to an assumption of strict causality and hence the relation can reasonably be employed for arbitrarily high energies. Our results for the radiative corrections to forward Compton scattering agree with the limit of Brown and Feynman's results rather than those of Schafroth.

[1] M. R. Schafroth, Helv. Phys. Acta **22**, 501 (1949); **23**, 542 (1950).
[2] L. M. Brown and R. P. Feynman, Phys. Rev. **85**, 231 (1952).
[3] J. S. Toll, Ph.D. thesis, Princeton University, May, 1952; J. S. Toll and J. A. Wheeler (to be published).

SA9. Lamb Shift for Spinless Electrons. Abraham Klein.* *Harvard University.*—In view of conflicting results

which have been published on the first-order Lamb shift for spinless electrons,[1] it was felt to be worthwhile to recompute this quantity using the most recent methods.[2] Our starting point was a mass operator associated with a modified Klein-Gordon equation, derived by the external source method of Schwinger.[3] The Lamb shift calculation was carried out by the operator technique which accords the same treatment to the low and high energy aspects of the phenomenon.[2] The result was checked by the more usual approach which separates relativistic and nonrelativistic contributions.[1] Our answer agrees with that of reference 1. By employing the second-order Dirac equation, we have further shown that the mass operator for the Dirac electron can be decomposed into two parts, one of which is substantially the Klein-Gordon result and reduces to it in the limit of vanishing spin; the other part remains finite in this limit.

* Junior Fellow, Society of Fellows.
[1] W. A. Newcomb and F. Rohrlich, Phys. Rev. **81**, 282 (1951).
[2] Karplus, Klein, and Schwinger, Phys. Rev. **86**, 288 (1952).
[3] J. Schwinger, Proc. Natl. Acad. Sci. US **37**, 452, 455 (1951).

SA10. On the Theory of the Lamb Shift. T. A. WELTON, *Oak Ridge National Laboratory.*—Recent work has made it appear that the present quantum electrodynamics (including vacuum polarization) predicts a level shift for hydrogen which is very close to the experimental value. There is, however, considerable reason to suspect that the Uehling contribution to the shift may be fictitious; and a question arises as to whether the present good agreement may not be coincidence. A parameterized quantum electrodynamics has been constructed, with a content apparently differing from existing theories of this type; and some of its consequences which bear on the above question will be displayed. It predicts the usual first-order level shift, but gives an alteration in the second-order contribution. This discrepancy has not been evaluated exactly, but its physical origin is clear, and arguments will be presented to show that it is of the same order of magnitude as the Uehling term, and probably of the same sign. In its present form, the theory can be made to yield a convergent vacuum polarization, although this requires the omission of the Uehling term. Unlike present theories, it yields a logarithmically diverging charge renormalization of electrodynamic (rather than positron) origin, which effect depends on the mass and state of motion of the electron.

SA11. On High Energy Nucleon Scattering and Isobars. R. B. RAPHAEL AND J. SCHWINGER, *Harvard University.*—The hypothesis of the charge independence of nuclear forces appears to be well substantiated for the ^1S state explored in low energy scattering experiments. To reconcile this assumption with the high energy $n-p$ and $p-p$ scattering data, one must devise an interaction which in virtue of the exclusion principle restriction on the states of identical particles is more effective in $p-p$ than in $n-p$ scattering. It has been proposed that a short-range spin-orbit interaction may fulfill these requirements.[1] The purpose of this note is to suggest that the spatially concentrated force which is manifest in the $p-p$ scattering data may be a consequence of the excitation, in close collisions, of nucleonic isobaric states. This process results in an effective velocity dependent interaction which includes a spin-orbit interaction if the coupling responsible for isobar excitation contains a tensor force. Thus, it may be possible to account for the scattering experiments by a phenomenological theory employing static, tensor interactions which stimulate transitions to excited states of the nucleons. Calculations to test this idea are in progress.

[1] K. M. Case and A. Pais, Phys. Rev. **80**, 203 (1950).

SA12. Variational Calculation of High Energy Scattering by a Yukawa Potential.* DAVID S. SAXON, *National Bureau of Standards,* AND E. GERJUOY, *University of Pittsburgh.*—Closed form approximations have been obtained for the differential scattering cross section for a central Yukawa potential using plane wave trial functions in Schwinger's variational formulation. Previous results[1] have been extended to include a general superposition of such plane waves. By taking advantage of the invariance of the Hamiltonian under rotations and inversion, independent integral equations (and thence variational expressions) can be obtained using the eigenfunctions of finite rotation operators as well as the parity operator. This corresponds to an expansion in a finite set of "partial waves" which becomes the usual expansion in spherical harmonics in the limiting case of infinitesimal rotation operators. In particular the rotation operator corresponding to a cyclic permutation of the coordinates was studied, this being equivalent to using a trial function consisting of a superposition of plane waves incident from both directions along three mutually perpendicular axes. The results agree reasonably well with exact solutions obtained by numerical integration of Schrödinger's equation, even for energies as low as 20 Mev, for a central Yukawa well appropriate to triplet $n-p$ interaction.

* Sponsored in part by the ONR.
[1] E. Gerjuoy and David S. Saxon, Phys. Rev. **85**, 939 (1952).

SA13. On the Use of Functionals in Evaluating S Matrix. JAMES L. ANDERSON, *Rutgers University.*—By making use of some simple ideas borrowed from the theory of functionals, it is possible to reduce considerably the problem of evaluating the S matrix, particularly when one is interested in involved processes and/or higher order terms. At the same time, these ideas allow one to obtain simple relationships between the S matrices for various processes, correct to all orders in $e^2/\hbar c$. The results of this investigation can be formulated as a set of simple rules. First, write down the S matrix for the vacuum to vacuum transition as a functional power series in the Feynman propagation kernels for the various types of quanta involved in the particular theory under consideration, i.e., photons, meson, etc. Now, every interaction between these quanta can be pictured as a region in space into which a certain number of quanta enter, and a certain number leave. For each pair of like quanta, take the functional derivative of the vacuum to vacuum S matrix with respect to the propagation kernel for this pair of quanta, multiply by their free particle wave functions, and integrate. The result will be the S matrix for the particular process envisioned.

SATURDAY MORNING AT 10:00

Paine Hall

(R. M. BOZORTH presiding)

Ferromagnetics and Ferroelectrics

T1. Magnetic Susceptibility and X-Ray Diffraction Measurements of Vanadium and Titanium Monoxides.* T. R. MCGUIRE AND SELMA GREENWALD, *Naval Ordnance Laboratory.*—Since all the monoxides of the first group transition metals so far reported are antiferromagnetic, the study was extended to VO and TiO. In the region 77°K to 300°K, VO

appears to be paramagnetic but it does not obey a Curie-Weiss law; instead the $1/\chi$ curve is concave facing the temperature axis. The magnetic susceptibility of TiO increases slowly with temperature and undergoes a sharp rise at 1000°C. At this temperature a specific heat anomaly has also been reported.[1] It is doubtful, however, that 1000°C is an antiferromagnetic Curie temperature, since the susceptibility continues to increase above 1000°C to 1400°C which was the highest temperature reached. In addition x-ray data gives no evidence of antiferromagnetic distortion of the crystal. The x-ray analysis did show the presence of two phases for TiO, one of which disappears if the material is heated to 1100°C in vacuum and then quenched.

* Supported in part by ONR.
[1] B. F. Naylor, J. Am. Chem. Soc. **68**, 1077 (1946).

T2. The Specific Heats of the Ferrites.* J. SAMUEL SMART, *Naval Ordnance Laboratory.*—The Néel theory[1] has been extended to calculate the discontinuities in the specific heats of ferrites at their Curie temperatures. In Néel's notation $\Delta C=(\Delta C)_0 Q(\lambda, a)$, where $a=\lambda\alpha-\mu\beta$, and $(\Delta C)_0$ is the specific heat discontinuity for ferromagnets and antiferromagnets obtained by treating the exchange interactions by a molecular field method.

$$Q(\lambda, a)=\frac{2\lambda\mu[a^2+4\lambda\mu]}{a^2+2\lambda\mu+(\mu-\lambda)a(a^2+4\lambda\mu)^{\frac{1}{2}}}.$$

The function Q takes on values between λ and unity so that the specific heat discontinuities in ferrites should in general be less than $(\Delta C)_0$. Theoretical curves for some mixed ferrites will be presented and the results compared with existing experimental data.

* Supported in part by the ONR.
[1] L. Néel, Ann. phys. **3**, 137 (1948).

T3. Electrical Conductivity of Magnetite at Low Temperatures.* B. A. CALHOUN, *M.I.T.*—The electrical conductivity of synthetic magnetite single crystals,[1] has been measured from room temperature to 40°K. Below the transition at 119°K, the activation energy decreases from 0.11 ev (90–78°K) to 0.061 ev (52–40°K). The conductivity below the transition is isotropic when the samples are cooled in a demagnetized state. Samples cooled through the transition in a magnetic field sufficient to saturate and then demagnetized show an anisotropic conductivity. The conductivity depends on the orientation of both the sample and the magnetic field. Verwey and his co-workers[2] suggested that the transition resulted from an ordering of the ferrous and ferric ions in the octahedral sites and proposed an ordered structure of orthorhombic symmetry. The observed anisotropy of the conductivity agrees with this model.

* Sponsored by the ONR, the Army Signal Corps, and the Air Force.
[1] J. Smiltens, J. Chem. Phys. **20**, 990 (1952).
[2] Verwey, Haayman, and Romeijn, J. Chem. Phys. **15**, 181 (1947).

T4. The Magnetic Susceptibilities of Hafnium, Gadolinium, and Manganese.* C. J. KRIESSMAN AND T. R. MCGUIRE, *Naval Ordnance Laboratory.*—The magnetic susceptibility of hafnium has been found to increase regularly from 0.42×10^{-6} at 25°C to 0.58×10^{-6} emu per gram at 1400°C. These data agree with a suggested explanation[1] of the temperature dependence of the susceptibility of the transition metals. Trombe's[2] measurements on the susceptibility of gadolinium have been extended from 400°C to 1000°C. Our data obey a normal Curie-Weiss law, $\chi_M=8.21/(T-25.5)$, which is similar to that found from Trombe's data. The low temperature maximum in the susceptibility-temperature curve of manganese reported by Serres[3] has been investigated. We find that the maximum occurs at about −150°C. This does not coincide either with the susceptibility maximum found by Serres or the neutron diffraction Curie point found by Shull.[4]

* Supported in part by ONR.
[1] C. J. Kriessman, ONR Conference on Magnetism, Univ. of Maryland, Sept. 1952. To be published in Revs. Modern Phys.
[2] F. Trombe, Ann. Physik **7**, 385 (1937).
[3] A. Serres, J. phys. et radium **9**, 377 (1938).
[4] C. G. Shull, ONR Conference on Magnetism, University of Maryland, September, 1952. To be published in Revs. Modern Phys.

T5. Transition Temperatures for Spherical Model Ferromagnets. MELVIN LAX, *Syracuse University.*—The Heisenberg model of ferromagnetism is replaced by a classical model in which the interaction between a pair of neighboring atoms is $-2JS(S+1)\boldsymbol{\epsilon}_i\cdot\boldsymbol{\epsilon}_j$ where S is the spin of any atom, J is the exchange integral and $\boldsymbol{\epsilon}_i$ is a classical unit vector. The partition function is evaluated using the spherical model,[1] and a transition is found in three dimensions but not in one or two dimensions. The transition temperatures T_c in units of kT_c/J are listed in the table below for several lattice types for the spin $\frac{1}{2}$ case. Corresponding results by P. R. Weiss[2] using the Bethe-Peierls method and by V. Zehler[3] using the Opechowski (1937) method are listed for comparison.

kT_c/J	Spherical	P. R. Weiss	V. Zehler
Simple cubic	1.98	1.85	1.93
Body-centered cubic	2.87	2.90	
Face-centered cubic	4.45		4.25
Body-centered spin 1	7.65	6.65	

The partly fortuitous success of the spherical model will be explained.

[1] T. H. Berlin and M. Kac, Phys. Rev. **86**, 821 (1952); M. Lax, J. Chem. Phys. **20**, 1351 (1952).
[2] P. R. Weiss, Phys. Rev. **74**, 1493 (1948).
[3] V. Zehler, Z. Naturforsch. **5**, 344 (1950).

T6. An Improved Spherical Treatment of the Ising Model. ALFRED LEVITAS AND MELVIN LAX, *Syracuse University.*—In the spherical treatment of the Ising Model problem[1] all dipoles are treated on an equal footing, and the partition sum is evaluated by relaxing the constraints on the lengths of the dipoles. A molecular field modification of the Spherical Model[2] in which one dipole is treated exactly and the remainder in Spherical Model, has been previously used to calculate the effective field on the dipole in question. The present analysis treats exactly a cluster consisting of a central dipole and its neighbors in the first shell, with the remainder of the lattice treated in Spherical Model. This improved Spherical Model yields a cluster distribution function which differs from the Bethe-Peierls result in that effective interactions between shell dipoles are obtained. Furthermore, there results an explicit expression for the shell molecular field. The self-consistency requirement of the Bethe-Peierls method is an over determining condition. The interactions in the remainder of the lattice may be modified by an unknown temperature dependent factor whose value is then determined by the self-consistency condition. This procedure reduces the errors inherent in treating the remainder of the lattice in Spherical Model.

[1] T. H. Berlin and M. Kac, Phys. Rev. **86**, 821 (1952); M. Lax, J. Chem. Phys. **20**, 1351 (1952).
[2] M. Lax, ONR Conference on Magnetism, University of Maryland, September, 1952. To be published in Revs. Modern Phys.

T7. Neutron Diffraction Studies on Various Ferromagnetic Alloys. M. K. WILKINSON AND C. G. SHULL, *Oak Ridge National Laboratory.*—The magnetic moment distribution within various ordered and disordered samples of binary ferromagnetic alloys has been studied by means of neutron diffraction patterns. Magnetic superstructure as well as chemical superstructure has been found for ordered samples of FeCo, Ni_3Fe and Ni_2Mn. From the absolute intensity of the magnetic superstructure lines, determined in two independent ways, and from the bulk magnetization data, it is possible to identify the magnetic moment associated with each atom in the alloy. Likewise for the disordered samples, a determination

of the magnetic disorder scattering has given information on the localized moments in the lattice. Values for the atomic moments deduced from such measurements will be presented.

T8. Ferroelectricity in Oxides of Fluorite Structure. W. R. Cook, Jr. and Hans Jaffe, *The Brush Development Company.*—The compounds $Cd_2Nb_2O_7$ and $Pb_2Nb_2O_7$ have been studied structurally and electrically. Regarding $Cd_2Nb_2O_7$, the high dielectric constant reported by Wainer and Wentworth[1] has been confirmed. On one body with a dielectric constant (K) of 450 at room temperature, we found a Curie point at -103°C where K reaches 2850. Hysteresis loops on this material taken at -196°C show a remanent charge density of 0.7 ± 0.2 microcoulomb per centimeter[2]. Powder x-ray diffraction patterns show a cubic fluorite structure with $a=5.185\pm0.003$A and one molecule per unit cell. This pattern can be accounted for by an arrangement with oxygens occupying statistically seven out of the eight anionic positions, and niobium and cadmium distributed statistically over the cationic positions of the fluorite structure. The analogous lead compound $Pb_2Nb_2O_7$ has a K of 110 at room temperature, and no Curie point above -196°C. The x-ray diffraction pattern shows a distorted fluorite structure of rhombohedral symmetry, with $a=5.285\pm0.003$A and $\alpha=89°15'$. The significance of these results in the study of ferroelectricity will be discussed.

[1] E. Wainer and C. Wentworth, J. Am. Ceram. Soc. **35**, 207–14 (1952).

T9. Thermal Conductivity Values for Barium Titanate.* Stanley S. Ballard and Kathryn A. McCarthy, *Tufts College.*—We are conducting a program on measuring the thermal conductivity of optical crystals as a function of temperature, over the temperature range -40°C to 150°C. The same techniques[1] have been applied to measuring the thermal conductivity of multicrystalline barium titanate, in view of the current interest[2] in its physical properties. The particular samples tested were furnished by the Brush Development Company of Cleveland, Ohio, and are designated as "Brush Ceramic *A*." Preliminary results give a thermal conductivity value at room temperature of about 3.2×10^{-3} cal sec^{-1} cm^{-1} C°$^{-1}$, and it was observed that the curve of thermal conductivity *versus* temperature is flat for at least forty degrees above room temperature. At temperatures just above 120°C, a much lower thermal conductivity was found; the value at 128°C is 1.6×10^{-3}. It was also observed that when the material cooled to room temperature, passing back through the Curie point, its thermal conductivity returned to the value previously determined.

* Assisted by a grant from the Penrose Fund of the American Philosophical Society.

[1] Ballard, McCarthy, and Davis, Rev. Sci. Instr. **21**, 905 (1950); McCarthy and Ballard, J. Opt. Soc. Am. **41**, 1062 (1951).

[2] A. von Hippel, Revs. Modern Phys. **22**, 221 (1950).

T10. Electret-Like Behavior in Polarized $BaTiO_3$ Ceramic. R. W. Thickens and R. J. MacDonald, *Armour Research Foundation.*—Electret-like behavior has been observed in polarized ceramic $BaTiO_3$ disks with fired electrodes. Measurements with a high impedance (5×10^9 ohms) vacuum tube voltmeter have shown that, after a short is removed, a potential between 1 and 100 volts builds up in approximately a minute and remains constant. The potential is sensitive to pressure and heating to the extent that heating on one side will make the potential go negative. Chopped light was found to produce an ac potential at the output of an electrometer. The thermal sensitivity of thick disks could be made to exceed 5 volts/watt. A tentative explanation is that the forming field is slowly decaying at a time dependent rate as postulated by Swann. Similarly, the ac output may be a pyroelectric effect resulting from thermally reversible changes in domain polarization. The ac output is greatly increased by thermal biasing near the Curie temperature.

T11. Double Hysteresis Loop of $BaTiO_3$ at the Curie Point. Walter J. Merz, *Bell Telephone Laboratories.*—It is known that the Curie point θ of the ferroelectric $BaTiO_3$ shifts to higher temperatures when a dc bias field is applied. Since in our crystals the transition is very sharp, we expect by applying an ac field at the Curie temperature that the crystal would become ferroelectric and nonferroelectric in the cycle of the ac field. This can be seen in the shape of the hysteresis loop at temperatures slightly above θ. In the center of the polarization P *versus* field E plot we observe a linear behavior corresponding to the paraelectric state of $BaTiO_3$ above θ. At both high voltage ends, however, we observe a hysteresis loop corresponding to the ferroelectric state. A change in temperature causes a change in size and shape of the double hysteresis loops, ranging from a line with curves at the ends (higher temperature) to two overlapping loops (lower temperature). The results obtained allow us to calculate the different constants in the free energy expression of Devonshire and Slater. One of the results shows that the transition is of the first order since the P^4 term turns out to be negative, and since a second-order transition cannot give double loops.

Saturday Morning at 10:00

Geology Lecture Room

(J. H. McMillen presiding)

Fluid Dynamics

U1. The Variation with Time of Flow Variables in the Shock Tube.* R. J. Emrich, J. E. Mack, and R. A. Shunk, *Lehigh University.*—The ideal theory of the flow in the shock tube after bursting of the diaphragm predicts steady flow in the regions between shock and cold front, and between cold front and rarefaction. Measurements of gas density have been made at various positions along a 3.5-cm diameter tube with the chrono-interferometer.[1] These show that the density increases steadily with time after the passage of the shock, increases rather abruptly with the passage of the cold front, and continues to rise further as the cold gas flows past. The density increase from just after the passage of the shock until just before the arrival of the cold front may be as great as 25 percent of the density increase across the shock front. Both the density increase across the shock and the density decrease across the rarefaction are less than predicted by the ideal theory. Indications from three types of pressure gauge suggest that the pressure continues to rise with time after passage of the shock.

* Supported by the ONR.

[1] Curtis, Emrich, and Mack, Phys. Rev. **87**, 913 (1952).

U2. Study of Transonic Flow Past Wedge Profiles by Hydraulic Analogy. E. V. Laitone and Helmer Nielsen,

University of California, Berkeley.—By utilizing the analogy existing between the gravity waves propagated in shallow water and the two-dimensional flow of a perfect gas with a specific heat ratio of 2, an experimental study was made of the transonic flow about symmetrical slender wedge profiles. The measured values were converted to the usual specific heat ratio of 1.4 by means of the transonic similarity relations. In the hydraulic analogy the local water depth corresponds to both the density and the temperature of the transonic gas flow. This permits direct evaluation of the equivalent gas flow velocity distribution by simply measuring the variation of the water depth. However, since the tests were made by towing the model through ¼-inch deep water (the best conditions for the analogy), it was practically impossible to measure the surrounding water depths by pressure measurements or simple depth gauges. Consequently, the water heights were measured by using electrical resistance probes of piano wire 0.004 inch in diameter. These water height measurements were used to compute the velocity distribution along the stagnation streamline from the detached shock wave to the nose of the wedge. Favorable agreement was found with linearized theoretical results for very slender wedges near a Mach number of unity.

U3. Transfer Processes in Isotropic Turbulence. C. M. TCHEN, *National Bureau of Standards.*—The transfer of energy through the spectrum is studied from a Fourier decomposition of the Navier-Stokes equation of motion. The derived transfer function suggests an interaction between two elements of fluid in such a way that the smaller element may be merged into the larger one, and as a result of intermingling, momentum is transmitted from the larger to the smaller element. The exchange of momentum is further studied statistically by introducing a probability of transition to describe the transport processes. The results attribute a dissipative character to the mechanism of transfer of energy, and confirm the Heisenberg hypothesis, by giving to it a physical foundation. Finally, the picture of exchange of momentum which serves as a basis of the formulation of the transfer function is interpreted from the Burgers model of turbulence.

U4. Propagation of Turbulence into an Irrotational Flow.* S. CORRSIN, *The Johns Hopkins University.*—The instantaneously sharp and irregular front which is always found to separate turbulent fluid from contiguous "nonturbulent" fluid at a free stream boundary (~the "intermittent zone") can be statistically described in part by (a) its mean rate of increase of wrinkle amplitude, and (b) its mean rate of propagation outward, relative to the mean fluid motion. For turbulent boundary layer, wake and jet it is found that (a) the increase of wrinkle amplitude can be roughly explained as a Lagrangian diffusion process, using the statistical properties of the turbulence in the fully turbulent zone; (b) the propagation, which must take place through direct viscous action in a "laminar superlayer" can be roughly predicted in terms of vorticity fluctuations in the fully turbulent zone.

* Work supported by the National Advisory Committee for Aeronautics.

U5. Theory of Nonhomogeneous Turbulence. JACK HELLER, *Princeton University.*—In the past decade significant advances have taken place which allow us to fully discuss the nature of isotropic homogeneous turbulence.[1,2] The general procedure is to find equations[3] for the shearing stresses $\langle u_i u_j \rangle_{Av}$. These equations, in the homogeneous case, contain two new sets of quantities: a triple turbulent velocity average and a turbulent pressure velocity average. These quantities are determined by dimensional arguments. In the case of nonhomogeneous compressible turbulence we do not have, in general, a constant stream velocity. We must also define a turbulent density. The density is broken up into two terms, one analogous to the stream velocity—its average is a slowly varying function of time; and a turbulent density analogous to the turbulent velocity—it is not positive definite and its average is zero. Dimensional arguments determine the triple turbulent velocity and turbulent pressure velocity average terms. The theory is then complete and problems of the growth as well as decay of turbulence can be discussed.

[1] W. Heisenberg, Z. Physik **124**, 628 (1948).
[2] G. K. Batchelor, Proc. Roy. Soc. (London) **195A**, 513 (1949).
[3] Th. von Karman and L. Howarth, Proc. Roy. Soc. (London) **164A**, 192 (1938).

U6. Discrete Transitions in Thermal Turbulence. WILLEM V. R. MALKUS, *Woods Hole Oceanographic Institution.*—A statistical mechanical criterion for steady-state fluid dynamics has yielded the approximate principle that the turbulent convection in a fluid between horizontal surfaces maximizes the heat transport. One then can deduce the mean heat transport, its spectrum, and the mean thermal gradients in terms of the smallest eddy size in the fluid. This paper deals with the determination of this smallest eddy size by a variational treatment of the characteristic value problem arising from the hydrodynamic equations. The slope of heat transport *versus* Rayleigh number and the discrete transitions in this slope are predicted for Prandtl numbers greater than one. Observations are presented which evidence agreement within the experimental error.

U7. Moment Method Solution of the Boltzmann Equation for the Rough Sphere Molecular Model. PHILIP M. MOSTOV, HAROLD GRAD, AND SIDNEY BOROWITZ, *New York University.*—The moment method solution[1] of the Boltzmann equation is extended to a molecular model with rotational degrees of freedom—the rough sphere molecule. Using rotational temperature and rotational heat flow, in addition to the 13 moments used by Grad for the point molecule, a system of 17 equations for the 17 moments is derived. This formulation provides a more realistic basis for the hydrodynamics of rarefied polyatomic gases than the conventional treatment of Pidduck and Kohler by the Chapman-Enskog method and is capable of treating phenomena whose interesting behavior depends on extreme variations in time or space, or on the rotational and translational temperatures being different. The equations are sufficiently general enough in scope to afford a more penetrating insight into the conditions under which the concepts of relaxation time constants and of transport type relations are valid. Special flows are examined leading to values for the shear viscosity, bulk viscosity, 4 distinct heat conduction coefficients; also for the relaxation time constants associated with stresses, translational heat flow, rotational heat flow, and rotational-translational temperature difference. Further applications and generalizations are in progress.

[1] H. Grad, Commun. Pure and Appl. Math. **2**, 331 (1949).

U8. The Statistical Mechanics of Irreversible Processes in Fluids. MELVILLE S. GREEN, *University of Maryland.*—This is an application of the ideas of a previous paper of the author[1] to irreversible processes in fluids. The phenomenological equations of these processes are derived and statistical mechanical expressions for the viscosity, diffusion, and heat conductivity coefficient, valid at all concentrations, are given. The gross variables are a finite number of the plane-wave expansion coefficients of the local particle, momentum, and energy densities. For a one-component fluid, the gross variables describing the local energy density are

$$\sum_{i=1}^{N}\left(\frac{p_i^2}{2m}+\tfrac{1}{2}\sum_{j\neq i}^{N} V(\mathbf{x}_i-\mathbf{x}_j)\right)\exp i\mathbf{k}\cdot\mathbf{x}_i,$$

where $\mathbf{p}_i$ and $\mathbf{x}_i$ are the momentum and position of the ith molecule, $V(\mathbf{x}_i-\mathbf{x}_j)$ the potential between the ith and jth molecules, m the mass of a molecule, and N their total number. $\mathbf{k}$ runs over a finite number of values which are all small com-

pared to the reciprocal mean distance between molecules. The coefficients of the irreversible processes are of the form $\int_0^\infty \varphi(\tau)d\tau$ where $\varphi(\tau)$ is the autocorrelation of a certain phase function.

[1] M. S. Green, J. Chem. Phys. **20**, 1281 (1952).

U9. (Abstract withdrawn.)

U10. The Boundary Layer on Spinning Axisymmetric Bodies.* ARTHUR N. TIFFORD AND SHENG TO CHU, *Ohio State University.*—A relatively general analysis of the boundary layer on spinning axisymmetric bodies has been made. When the Reynolds number is large as compared with unity; when the thickness ratio of the body is not too small; when the spinning velocity is less than the free-stream velocity, the significant results are that the three-dimensional motion is simply expressible in terms of a two-dimensional boundary layer and that the spinning component of the velocity boundary layer is simply related to the thermal boundary layer.

* This research was supported by The Flight Research Laboratory of the Research and Development Command of the USAF.

U11. The Blasius and Weyl Constants in Boundary Layer Theory. DANIEL SHANKS, *Naval Ordnance Laboratory.*—The classical Blasius problem is solved analytically and the Blasius, and Weyl constants α and R are computed. One finds, from the series solution of $f(x)f'''(x)+f'''(x)=0, f(0)=f'(0)=0, f''(0)=1$, that R, the radius of convergence, is 3.12735. This agrees with the result, $3.1<R<3.18$, of Ostrowski.[1] For a selected argument $x_0=30^{\frac{1}{2}}$, the very slowly convergent series is summed by a nonlinear transformation previously reported.[2] Further, sharp upper and lower bounds for $f'(\infty)-f'(x_0)$ are obtained in terms of a continued fraction. The final result, that $1.328228<\alpha<1.328230$, disagrees only slightly with Goldstein's and Howarth's[3] values: 1.32824 and 1.328242.

[1] Ostrowski, Compt. rend. **T227**, 580 (1948).
[2] Daniel Shanks, Phys. Rev. **76**, 876 (1949).
[3] Howarth, Proc. Roy. Soc. (London) **A164**, 551 (1938).

SATURDAY MORNING AT 10:00

Fogg Museum

(N. F. RAMSEY presiding)

Molecular Beam Experiments; Various Topics in Nuclear Physics

UA1. The Fine Structure of Singly Ionized Helium.* PAUL F. YERGIN,† WILLIS E. LAMB, JR.,‡ EDGAR LIPWORTH, AND ROBERT NOVICK, *Columbia University.*—A pulsed method has been developed to measure the $2^3S_1-2^3P_1$ separation in singly ionized helium. The helium atoms are excited to the metastable 2^3S_1 state of the ion by a microsecond pulse of electrons of about 200-ev energy, and after the bombardment is over and the radiation from the excitation of nonmetastable states of the atom and ion have died away, a pulse of microwave power is applied to induce the $2^3P_1-2^3S_1$ transition, which is followed immediately by spontaneous emission of a 40.8-ev photon associated with the $1^2S_{\frac{1}{2}}-2^2S_{\frac{1}{2}}$ transition. The photons are observed by counting photoelectrons with high speed counters gated on for microsecond intervals synchronously with the applications of the pulses of microwave power. Two different levels of rf power are used alternately to provide a means of normalizing the data for variations in the population of the 2^3S_1 state. In the course of the measurements some information has been obtained on satellite pulses in a photomultiplier tube. The measured value of the level separation is $14\,021\pm60$ Mc/sec which agrees with the measurement by Lamb and Skinner and is in good agreement with the best available theoretical prediction.

* Work supported jointly by the Signal Corps and the ONR Research.
† Present address: Department of Physics, University of Pennsylvania, Philadelphia 4, Pennsylvania.
‡ Present address: Department of Physics, Stanford University, Stanford, California.

UA2. Atomic Beam Magnetic Resonance Experiments on Helium 3.† GABRIEL WEINREICH* AND VERNON W. HUGHES,‡ *Columbia University.*—An atomic beam of $1s2s\ ^3S_1$ metastable atoms of He^3 is produced from a discharge tube in a manner similar to that used for He^4.[1,2] Because of the rarity of the isotope, a recirculation system,[3] which continuously pumps back into the discharge tube the gas that leaks into the vacuum chamber, has been added to the apparatus. Purification of the gas is effected by chemical action of the aluminum discharge tube electrodes. By this method, a sample of He^3 of 1.5 cc NTP can be run for an indefinite length of time. Rough measurements of transitions with $\Delta F=0$, $\Delta m_F=\pm1$ at low fields verify[4,5] that the nuclear spin of He^3 is $\frac{1}{2}$. Measurements on the HFS splitting of the state are in progress.

† Research supported in part by the ONR.
* AEC predoctoral fellow.
‡ Now at the University of Pennsylvania, Philadelphia, Pennsylvania.
[1] Vernon Hughes and Gardiner Tucker, Phys. Rev. **82**, 322 (1951).
[2] Tucker, Hughes, Rhoderick, and Weinreich, Phys. Rev. **86**, 618 (1952).
[3] Edward B. Nelson and John E. Nafe, Phys. Rev. **75**, 1194 (1949).
[4] Herbert L. Anderson, Phys. Rev. **76**, 1460 (1949).
[5] Fred, Tompkins, Brody, and Hammermesh, Phys. Rev. **82**, 406 (1951).

UA3. Direct Comparison of m/e for the Positron and the Electron.* L. A. PAGE, P. STEHLE, AND S. B. GUNST, *University of Pittsburgh.*—A double-focusing mass spectrometer employs a linear velocity selector with crossed E and H fields, in series with a magnetic momentum selector in the same field H. The resolution width in $\log(m/e)$ is 4×10^{-3}. A filament injects 55-kv electrons. For constant H, the value of E to focus electrons, E^-, is found. Next, with fixed geometry and H, positrons from Na^{22} are passed through the instrument in the opposite direction, E being reversed and readjusted if necessary, to focus positrons at say $E^-+\Delta E$. Many such runs (which remove effects of secular drifts in temperature, magnetic field, etc., and give favorable counting statistics for positrons) yield

an average $\Delta E/E$. The result is

$$\frac{(m/e)^- - (m/e)^+}{m/e} = \frac{1}{1-v^2/c^2}\frac{\Delta E}{E} = (26 \pm 71) \times 10^{-6}.$$

The uncertainty is the standard deviation from positron counting, and from a parameter depending thereon. For seventeen evaluations of $\Delta E/E$ the rms deviation is within the counting error. Thus, the electron and positron m/e are found identical within 71 parts per million standard deviation.

* Work supported in part by the ONR, and done in the Sarah Mellon Scaife Radiation Laboratory.

UA4. Energy Loss of Positrons and Electrons.* F. ROHRLICH AND B. C. CARLSON, *Princeton University.*—Calculations show that the average rate of energy loss of positrons passing through matter exceeds that of electrons below about 350 kev. The situation is reversed above this energy. At 100 kev, the positron-electron difference is about 4 percent in Al, 6 percent in Pb. At 2 Mev, it is about −2.5 percent in Al, −3.5 percent in Pb. This effect is primarily due to the difference in the exchange interaction terms and in the maximum possible energy transfer in a single collision. Therefore, only large angle collisions contribute to the ionization loss difference. In calculations of transmission, range, and multiple scattering, the positron-electron difference which arises from elastic scattering will be modified by the difference in energy loss considered here. The dependence of this modification on energy and atomic number will be discussed, and numerical estimates will be presented.

* This work was supported by the AEC and the Higgins Scientific Trust Fund.

UA5. A Direct Measurement of the Effect of Polarization on the Energy Losses of Fast Electrons.* E. L. GOLDWASSER, F. E. MILLS,† AND T. R. ROBILLARD, *University of Illinois.*—Monoenergetic 15.7-Mev electrons from the 22-Mev betatron were incident upon solid and gaseous absorbers of about 1 g/cm² thickness. The energy of the electrons after passing through the absorbers was analyzed by a 70° magnetic spectrometer. The most probable energy loss in a solid material has been compared with the most probable loss in a gas of the same chemical composition. Two different sets of absorbers were used, namely, (1) perfluorocyclobutane gas and its polymer "Teflon" tetrafluoroethylene resin, and (2) chlorotrifluoroethylene gas and its polymer "Kel-F" plastic. The most probable energy losses in the solids are in agreement with Landau's[1] theory corrected for the effect of polarization as calculated by Fermi.[2] The most probable energy losses in the gases are in agreement with the Landau theory with no polarization correction.

* Work supported in part by ONR.
† AEC Predoctoral Fellow.
[1] L. Landau, J. Phys. (U.S.S.R.) **8**, 201 (1944).
[2] E. Fermi, Phys. Rev. **57**, 485 (1940).

UA6. Energy Loss Distribution of 624-Kev Electrons in Thin Foils.* B. HILDEBRAND,† *Rensselaer Polytechnic Institute.*—A double focusing beta-ray spectrometer[1] has been used to study the distribution of energy loss of fast electrons in thin foils. The 624 internal conversion K line of Ba^{137} is used as the electron source. The foils are placed directly in front of Cs^{137} sources of total area density 100–250 μg/cm². The half-angle of acceptance of the spectrometer is 5°. The energy loss distribution has been determined for the case of 13.9 mg/cm² aluminum foil in detail. A distribution half-width and most probable energy loss study has been made for 2–33 mg/cm² aluminum. Comparison of the observed distribution with those Landau[2] and Blunck-Leisegang[3] indicates greater agreement with the latter. The observed probable energy loss and the Blunck-Leisegang probable energy loss are brought into agreement by use of the polarization correction of Halpern and Hall.[4]

* Supported in part by the AEC and the RPI Research Fund.
† Now at Westinghouse Electric Corporation, Bloomfield, New Jersey.
[1] Kurie, Osoba, and Slack, Rev. Sci. Instr. **19**, 771 (1948).
[2] L. Landau, J. Phys. (U.S.S.R.) **8**, 201 (1944).
[3] O. Blunck and S. Leisegang, Z. Physik **128**, 500 (1950).
[4] O. Halpern and H. Hall, Phys. Rev. **73**, 477 (1948).

UA7. e/m for 385-Mev Protons.* D. J. GROVE AND J. G. FOX, *Carnegie Institute of Technology.*—The charge to mass ratio for 385-Mev protons having $\beta \cong 0.7$ has been measured using the internal beam of the C. I. T. 140-inch synchrocyclotron. A 0.00033-inch W wire perpendicular to the pole faces at 61-inch radius served to sample the proton beam by scattering a small percentage of the protons into a scintillation counter located above the mid-plane and at approximately the same radius. Examination of the signal from the counter yielded the location of the equilibrium orbit. A frequency discriminator permitted determination of the angular frequency corresponding to protons in this orbit, and this together with measurement of the magnetic field yielded e/m, since $(e/m)_1 = \omega c/H$. A careful measurement of the location of the magnetic center fixed the radius of the equilibrium orbit so that the above value of e/m could be compared with that obtained from the relativistic expression $(e/m)_2 = c/m_0(1-\omega^2 r^2/c^2)^{\frac{1}{2}}$. From 64 measurements we obtain for $(e/m_1 - e/m_2)/e/m_2$ the preliminary value of -0.0006 ± 0.001.

* Supported in part by the AEC.

UA8. The Energy Loss of Heavy Charged Particles in Gases.* PETER K. WEYL, *University of Chicago.*—The differential energy loss of protons, deuterons, alpha-particles, and neon ions from 50 to 500 kev is under investigation in air, argon, and other gases. The ions produced by the Cockroft-Walton accelerator, after being magnetically analyzed, traverse a differentially pumped gas chamber and then enter a cylindrical electrostatic analyzer. There are no foils in the path of the beam. This insures the absence of any other mechanism of degradation in energy except loss of energy in the gas and permits the study to be extended to low energies and high Z particles which have relatively large dE/dx values. The analyzer measures the energy of the particles first without gas and then with gas in the chamber. From the difference in energy, a measurement of the pressure and temperature of the gas and a knowledge of the effective length of the gas chamber, the dE/dx is determined. The results will be presented.

* This work has been supported in part by the AEC.

UA9. Techniques in Isotopic Abundance Measurements on Elements of Group IV. J. H. REYNOLDS AND T. J. YPSILANTIS, *University of California, Berkeley.*—Certain of the complex fluorides are convenient compounds for isotopic assay of the metals of Group IV, especially if samples are small, as in tracer studies. For the lighter metals having gaseous tetrahalides, the barium salt is prepared. When heated, this evolves the tetrahalide leaving a nonvolatile BaF_2 residue. For example, $BaGeF_6 \rightarrow GeF_4\uparrow + BaF_2$. With very small samples, the decomposition can be carried out within the vacuum envelope of the mass spectrometer and the tetrahalide can be conducted directly to the region where it is ionized by electron bombardment. For the heavier metals, the ammonium salt is prepared and used with a crucible ion source. Preheating of the crucible drives off ammonium fluoride leaving a residue of the less volatile tetrahalide which can then be sublimed into the electron beam. For example, $(NH_4)_2HfF_6 \rightarrow 2NH_4F\uparrow + HfF_4\uparrow$. Advantages of these techniques are that the complex fluorides are easily prepared, even in small quantities, by simple "wet" chemistry, and are completely stable except at the elevated temperatures required for decomposition. Natural isotope abundances for certain of the Group IV metals will be presented.

SATURDAY AFTERNOON AT 2:00

Paine Hall

(J. C. HUNSAKER presiding)

Business Meeting of the Division of Fluid Dynamics

Symposium of the Division of Fluid Dynamics

V1. Turbulent Processes as Observed in Boundary Layer and Type. G. B. SCHUBAUER, *National Bureau of Standards.* (30 min.)

V2. Turbulent Boundary Layers Having Equilibrium Velocity Profiles in Adverse Pressure Gradients. F. H. CLAUSER, *The Johns Hopkins University.* (30 min.)

V3. Stability of the Boundary Layer at Supersonic Speeds. C. C. LIN, *M.I.T.* (30 min.)

V4. Skin Friction in Supersonic and High Subsonic Flow. H. W. LIEPMANN, *California Institute of Technology.* (30 min.)

SATURDAY AFTERNOON AT 2:00

Pierce 110

(R. SMOLUCHOWSKI presiding)

Metals

VA1. Specific Heat Measurements on Pure Metals at Low Temperatures. M. HOROWITZ AND J. G. DAUNT, *The Ohio State University.*—Using the semi-automatic recording calorimeter previously described,[1] measurements have been made in the temperature range 1°K to 20°K on the specific heat of pure molybdenum and tungsten. At the lowest temperatures for molybdenum $\theta=444$°K and $\gamma=5.1\times10^{-4}$ cal/mole-deg^2 and for tungsten $\theta=270$°K and $\gamma=1.8\times10^{-4}$ cal/mole-deg^2. These new and extensive measurements on tungsten indicate the need for revising the previously quoted data.[2] The results are compared with theory for these and other transition elements.

[1] Horowitz, Silvidi, Malaker, and Daunt, Phys. Rev. **86**, 818 (1952).
[2] A. A. Silvidi and J. G. Daunt, Phys. Rev. **77**, 125 (1950).

VA2. Apparatus for Measuring the Thermal Conductivity of Metals in Vacuum at High Temperatures. MARVIN MOSKOWITZ,* *Sylvania Electric Products Inc.*—An apparatus has been designed and constructed for the measurement in vacuum of the thermal conductivity of metals at high temperatures. The method consists of measuring the axial temperature gradients and the flow of heat along a cylindrical bar. One end is heated by a resistance heater while a constant-flow water calorimeter at the other measures the heat flow; the gradients are determined by thermocouples peened into slots in the bar. Guard heaters surrounding the specimen along its entire length reduce radial loss of heat adequately. The equipment permits a direct determination of thermal conductivity without reliance on previously established data for metals used as standards in other equipment of this type.[1] Measurements have been made on nickel up to 530°C and the data agree with published values of the thermal conductivity of nickel.

* Work done under AEC contract.
[1] Van Dusen and Shelton, "Apparatus for measuring thermal conductivity of metals up to 600°C," Bur. Standards Research Paper RP668 (1934).

VA3. Soft X-Ray Absorption of Iron and of Iron Oxide.* D. E. CARTER AND M. P. GIVENS, *University of Rochester.*—The soft x-ray absorption of thin films of iron and of iron oxide (Fe_2O_3) has been studied in the wavelength region 160 to 330A. A grazing-incidence vacuum ultraviolet spectrograph was used in the manner described by Skinner and Johnston.[1] The films, which were deposited on celluloid by vacuum evaporation, were of thicknesses 220 to 490A. The results show an absorption edge at about 230A for iron. The curve for the iron oxide seems to be quite similar to that for the iron.

* Supported by ONR.
[1] H. W. B. Skinner and J. E. Johnston, Proc. Roy. Soc. (London) **A161**, 420 (1937).

VA4. Theory of the Resistance Minimum in Metals. J. E. GOLDMAN, *Carnegie Institute of Technology.*—The observed presence of a resistance minimum in Cu, Ag, Au, and Mg containing nonparamagnetic impurities[1] and the recent susceptibility and magnetoresistance measurements of Thomas and Mendoza[2] suggest that a mechanism other than that proposed by Gerritsen and Korringa is probably involved. We propose an alternative mechanism based on the suggested presence of nonoverlapping localized impurity states in a metal which have been discussed by Friedel and employed by the author[3] to explain the anomalous properties of copper-rich Ni-Cu alloys. If the gap separating an unoccupied impurity state from the top of a filled band $\Delta\epsilon$ is narrow, above a critical temperature T_m defined by $kT_m=\Delta\epsilon$, electrons will be excited into these states and hole conduction from an otherwise filled band (*3d* band in Cu, etc.) would supplement the ordinary $s-p$ electronic conduction, but this contribution would disappear at lower temperatures giving rise to the observed minimum. The gap must be very small for this effect to be evident, i.e., $T_m\sim5$°K, since only at those low temperatures would the $s-d$ scattering which would normally accompany this process be negligible. The theoretical and experimental basis for the proposed mechanism will be discussed.

[1] D. K. C. MacDonald, Phys. Rev. **88**, 148 (1952); also, Schenectady Cryogenics Conference, October, 1952.
[2] J. G. Thomas and E. Mendoza, Phil. Mag. **43**, 900 (1952).
[3] J. E. Goldman, Phys. Rev. **82**, 339 (1951).

VA5. Solubility of Silicon in Gallium and Indium. PAUL H. KECK, *Signal Corps Engineering Laboratories.*—The solubilities of silicon in gallium and in indium were determined over a wide temperature range. If the logarithms of the solubilities are plotted against the inversed absolute temperatures, straight lines are obtained the slopes of which yield the heats of solution. For the investigated system, it was found that the heats of solution are approximately proportional to the 3^d power of the radii of the solvent atoms. Upon slow cooling of

the saturated solutions, silicon crystals of fair purity were obtained. The electrical characteristics of such crystals are discussed.

VA6. Energy Bands in Niobium Metal.* ELEANOR TREFFIZ,† *Ohio State University.*—Karringa's "scattering matrix" method is used,[1] which has the advantage that a large part of the numerical work depends only on the lattice type and not on the particular element. The scattering matrix itself must be calculated for the element chosen. This involves a solution of Schrödinger's Equation in the field of the atom care and the expansion of the solution in spherical Bessel and Hankel functions in the field-free region between the atoms. The construction of a potential function is discussed. The usual spherically symmetrical approximations give a discontinuous, rather than a zero, derivative midway between the atoms. The difficulties which arise from this are similar to those met in Slater's cellular method.[2] A mixture of Thomas-Fermi potential (for the core electrons) and Hartree potential (for the valence electrons) including exchange, was chosen for the actual calculations.

* Supported by ONR.
† Ohio State University Postdoctoral Fellow.
[1] Korringa, Physica **13**, 392 (1947).
[2] Compare Fred C. Von der Lage and H. A. Bethe, Phys. Rev. **71**, 612 (1947).

VA7. Temperature Dependence of Secondary Electron Emission from Tantalum, Platinum, and Graphite. E. J. STERNGLASS, *Cornell University.**—Experimental evidence has been obtained for a decrease in the yield (Δ) of low energy (<50 ev) secondary electrons (SE) with increasing absolute temperature (T) for Ta, Pt, and graphite. A spherical collector with a suppressor screen permitted simultaneous measurement of the SE energy distribution and the number of back-scattered electrons as checks on the performance of the equipment. Reproducible yield curves were obtained between 25°C and 500°C for primary energies (V) from 200 to 3500 volts. Possible effects of the target heater magnetic field were avoided by making measurements with the heater current off. The decrease in Δ is greatest near the peak of the yield curve, amounting to 0.7, 0.6, and 0.5 percent per °K for Pt, Ta, and graphite, respectively. The change in Δ is orders of magnitude smaller at the lower cross-over point where the effect had been searched for previously. The empirical data fit an equation of the form $\Delta = \text{const} \times V \exp -\beta_0(1+\alpha T) V^{\frac{1}{2}}$, where β_0 is a constant proportional to the absorption cross section for SE in each material and α has the value 3×10^{-4}/°K$\pm$20 percent for Ta, Pt, and graphite. This gives direct evidence for an exponential absorption law of SE in metals and graphite.

* Now at Westinghouse Research Laboratories.

SATURDAY AFTERNOON AT 2:00

Fogg Museum

(W. W. BUECHNER presiding)

Invited Paper

W1. Nuclear Reactions with 25-Mev Nitrogen Nuclei. ALEXANDER ZUCKER, *Oak Ridge National Laboratory.* (30 min.)

Reactions of Transmutation; Photoelectric Effect

W2. The Tritium (p, γ) Reaction. J. E. PERRY, JR., AND S. J. BAME, JR., *Los Alamos Scientific Laboratory.*—The production of 20-Mev gamma-rays by proton bombardment of tritium gas has been studied using NaI scintillation counters for gamma-detection. All yields were computed from the observed differential pulse-height distributions. These distributions showed the appropriate shift of maximum pulse height with gamma-energy. In angular distribution measurements the Doppler shift of gamma-frequency was observed. Relative yields were computed by counting all pulses greater than a minimum value, which was varied appropriately with gamma-energy. Based on the assumption that the differential pulse height distribution changes scale and not shape over the energy range 19.8 to 23 Mev, the following preliminary results were obtained. (1) The 90° absolute cross sections form a smooth curve with the values 4, 8, 10, and 11×10^{-30} cm² per sterradian at 1, 2, 3, and 4.3 Mev, respectively. (The absolute cross section was measured at 1 Mev by extrapolating the pulse-height distribution to zero pulse height, and was extended to higher energies by a 90° relative yield curve.) (2) The angular distribution is approximately $\sin 2\theta$, with the 0° yield 1 or 2 percent of the 90° yield. (3) There is some asymmetry about 90°, the ratio 60°/120° being about 1.2.

W3. High Energy Photoproton Production. A. WATTENBERG, B. T. FELD, AND R. D. GODBOLE, *M.I.T.**—Studies have been made on the angular and energy distributions of high energy protons from Be and C targets bombarded with 330-Mev bremsstrahlung from the synchrotron. Protons of energy 126, 169, and 203 Mev were detected by a scintillator telescope. The yields were observed to decrease monotonically with increasing angle from 15°, the decrease being sharper the higher the proton energy. The cross sections per proton in the nucleus and the angular distributions were the same for Be and C. The proton energy distribution from 126 to 290 Mev is in rough qualitative but poor quantitative agreement with previous observations, and disagrees with all published theories.

* This work was supported in part by the joint support of the ONR and the AEC.

W4. Photoproduction of Protons by Monoenergetic 190 Mev γ-Rays.* J. W. WEIL† AND B. D. MCDANIEL, *Cornell University.*—Using the recently described technique for selecting monoenergetic γ-rays from the bremsstrahlung beam of the Cornell synchrotron,[1] we have studied the photoproduction of protons from carbon. The γ-ray spectrum employed had an energy of 190$\pm$30 Mev. Protons were detected using a three-crystal telescope with the first two counters in coincidence and the last one in anticoincidence to distinguish protons by their dE/dx for a fixed residual range. The detected protons were then counted in coincidence with the selected quanta, so that only protons produced by essentially monoenergetic γ-rays were recorded. The energy spectrum of protons emitted at an angle of 60 degrees was studied. Results essentially in agreement with the subtraction technique of Perry and Keck[2] were obtained. Angular distribution measurements by the monoenergetic quanta technique are now in progress. The fast coincidence circuit employed in selecting the monoenergetic

quanta contained an internal monitoring system in order to allow observation of any changes in detection efficiency.

* Work supported by the ONR.
† USAEC Predoctoral Fellow.
[1] J. W. Weil and B. D. McDaniel, Phys. Rev. **86**, 582 (1952).
[2] A. M. Perry and J. C. Keck, Phys. Rev. **86**, 629 (1952).

W5. Fast Neutron Reactions in Oxygen and Neon. D. I. WANKLYN, *McGill University.*—Oxygen and neon have been bombarded in a Wilson Chamber with neutrons of energies up to 45 Mev obtained from the proton bombardment of Beryllium in the McGill synchrocyclotron. Reactions have been identified by a method based in part on a knowledge of the direction of the incident neutron and its maximum possible energy. This method is discussed and a description is given of the neutron channel and an original apparatus for making measurements of the stars. Among the stars observed, the following reactions have been found: $O^{16}(n, n\alpha)C^{12}$, $O^{16}(n, n4\alpha)$, $Ne^{20}(n, n\alpha)O^{16}$, $Ne^{20}(n, n2\alpha)C^{12}$, and some evidence has been obtained for the reaction $Ne^{20}(n, n5\alpha)$. Stars arising from the reaction $O^{16}(n, n4\alpha)$ have been analyzed to determine the roles played by C^{12} and Be^8 as intermediate stages in the disintegration. The results of this analysis together with evidence of anisotropy in the angular distribution of the emergent neutrons is given.

W6. Disintegration of Carbon by Fast Neutrons. J. DAVID JACKSON AND D. I. WANKLYN, *McGill University.*—The reaction $C^{12}(n, n)3\alpha$ has been studied with the cloud chamber and neutron beam described in the preceding abstract. The incident neutron energies ranged from 8 to 40 Mev, eighty percent of the events analyzed lying in the interval 8 to 25 Mev. The measurements allow the determination of the incident neutron energy, the outgoing neutron energy and angle, as well as the energies and angles of the alpha-particles. Evidence based on the energy distribution of the emerging particles shows that the reaction proceeds to an appreciable extent by the formation of a compound nucleus at neutron energies less than 20 Mev while at higher energies the mechanism is excitation of C^{12} by inelastic collision. The possible formation of Be^8 in its various states as an intermediate step in the reaction has been investigated. In forty percent of the events Be^8 occurs in its ground state. All these events arise from the 9.7 Mev level in C^{12} with an observed half-width of 1.6 Mev, and show no dependence on incident neutron energy. Conversely, the 9.7 Mev level in C^{12} decays directly into three alphas less than 25 percent of the time. The width of the level and the relative probabilities of decay by the two modes are consistent with simple theoretical estimates. Evidence for the formation of Be^8 in excited states will also be discussed.

W7. Angular Distribution and Energy Spectrum of Charged Particles Produced by 14-Mev Neutrons on Li^6 and Li^7.† G. M. FRYE AND L. ROSEN, *Los Alamos Scientific Laboratory.*—Separated isotopes of Li^6 and Li^7 have been bombarded by a collimated beam of 14-Mev neutrons and the resulting charged particles detected in the angular region from 10° to 160° by nuclear track plates. Data were obtained at 0° by removing the collimator and placing the Li target closer to the neutron source. Then the background was <20 percent. In Li^6 the $Li^6(n, d)He^5$ reaction predominates[1] with an angular distribution peaked in the forward direction. This indicates the process is one of inverse stripping[2] or pick-up. That this group of tracks is due to $Li^6(n, d)He^5$ and not $Li^6(n, p)He^{6*}$, which could give tracks of the same range, was determined by grain counting. A continuous distribution of lower energy deuterons is found, probably owing to the three particle disintegration $Li^6(n, dn)He^4$. The $Li^6(n, t)He^4$ and $Li^7(n, t)He^5$ reactions are also observed. Values for the total cross sections and angular distributions will be given.

† Work performed under the auspices of the AEC.
[1] F. L. Ribe, Phys. Rev. **87**, 205 (1952).
[2] S. T. Butler and E. E. Salpeter, Phys. Rev. **88**, 133 (1952).

W8. The Angular Distribution of the Long Range Alpha-Particles from $F^{19}(p, \alpha)O^{16}$. E. B. PAUL, R. L. CLARKE, AND W. T. SHARP, *Chalk River Laboratories.*—The angular distribution of the long-range alpha-particles resulting from proton bombardment of fluorine has been determined for proton energies between 1.3 and 2.0 Mev at 0.05-Mev intervals. The target consisted of CaF_2 evaporated onto a 20-mil aluminum backing. The alpha-particles were detected in a proportional counter set at angles to the proton beam between 0° and 145°. Shorter-range particles were excluded from the counter by absorbers. Near the previously reported[1] resonances, the coefficients a_n of the expansion of the observed angular distribution referred to the c.m. system in Legendre polynomials are:

E_p	a_0	a_1	a_2	a_3	a_4
1.396	0.75	−0.20	0.44	−0.2	−0.3
1.749	3.02	3.21	0.79	(0.1)	(0.1)
1.915	3.61	3.11	3.04	(−0.4)	(0.0)

Our results indicate spin and parity assignments of 0+ and 1− for the levels of Ne^{20} corresponding to $E_p = 1.73$ and 1.91 Mev, respectively and are in agreement with the assignment of 2+ for the level corresponding to $E_p = 1.38$ Mev as proposed by Chao.[2]

[1] E. B. Paul and R. L. Clarke, Bull. Am. Phys. Soc. **27**, No. 5, 7 (1952).
[2] C. Y. Chao, Phys. Rev. **80**, 1035 (1950).

W9. Angular Distributions of (d, p) Reactions on P^{31}, Cl^{35}, V^{51}, and Sc^{45}.* J. S. KING AND E. H. BEACH, *University of Michigan.*—By using the 7.8-Mev deuteron beam from the Michigan 42″ cyclotron, angular distribution studies have been made on the above targets. Proton energies were measured using the range-energy technique and a dual proportional counter telescope in coincidence. The scattering chamber was designed to provide continuously variable scattering angles from 20 to 160 degrees, with special angles at 0, 10.8, and 15 degrees. Results of the work done on the ground states of P^{32}, Cl^{36}, and V^{52}, and previously reported, will be reviewed and interpreted by means of Butler's theory. Except for small admixtures, the data indicate that the stripped neutron is accepted with an angular momentum of 2 for P^{32}, 2 for Cl^{36}, and 1 for V^{52}. More recent data show that Sc^{46} has an l_n of 3. These findings are in good agreement with the shell model picture. In addition, angular distributions have been made on some of the excited states of P^{32}, namely, for Q_2, Q_3, Q_4, Q_6, Q_7, Q_{12}, and Q_{13}. Some of these seem to require excitation of the core for their interpretation.

* Supported in part by the AEC.

W10. Angular Distributions of (d, p) Reactions. CLAYTON F. BLACK, *M.I.T.*—Application of Butler's theory to the

TABLE I.

Reaction	Level	Orbital angular momentum
$Be^9(d, p)Be^{10}$	ground state	$l_n = 1$
	3.37 Mev	1
$C^{12}(d, p)C^{13}$	g.s.	1
	3.11	0
	3.88	2
$F^{19}(d, p)F^{20}$	g.s.	2
$Al^{27}(d, p)Al^{28}$	g.s. and 0.031 Mev	0
$Si^{28}(d, p)Si^{29}$	g.s.	0
	1.29	2
$P^{31}(d, p)P^{32}$	g.s.	2
$S^{32}(d, p)S^{33}$	g.s.	2
	0.79	0
$Cr^{50}(d, p)Cr^{51}$	g.s.	1
$Fe^{54}(d, p)Fe^{55}$	g.s.	1
	1.38	1
	2.56	1

measured proton angular distribution of (d, p) reactions determines the orbital angular momentum of the captured neutron. Results using 14.3-Mev deuterons from the M.I.T. cyclotron are summarized in Table I.

W11. Photoelectron Ejection by 0.51 Mev Polarized Photons.* FRANK L. HEREFORD AND JEROME P. KEUPER, *University of Virginia.*—Recent experiments[1] on the directional distribution of photoelectrons produced by linearly polarized photons indicated larger azimuthal asymmetry than predicted by the relativistically computed cross section.[2] Although demonstrating asymmetry, the method did not distinguish between photoemission coplanar and orthogonal to the polarization vector of incident photons. Further data have been obtained utilizing again the polarization property of annihilation quanta (**K** and $-$**K**). One channel of a fast scintillation counter coincidence circuit detected photon **K** Compton scattered through $\pi/2$ radians and in a given azimuth direction Φ_1. Through the Klein-Nishina formula and the known polarization correlation between annihilation quanta, this observation yields a partial analysis of the polarization state of photon $-$**K**. A second coincidence channel detected photoelectrons ejected from Pb foils by photon $-$**K** in the relative azimuth direction $\Phi_2-\Phi_1$. Coincidence rates were measured for various orientations $\Phi_2-\Phi_1$. The data demonstrate a more predominate emission coplanar with the polarization vector of photon $-$**K** than predicted by the theoretical cross section. A possible explanation of the discrepancy lies in the approximate nature of the theory.

* Supported by U.S.N. Bureau of Ordnance.
[1] F. L. Hereford, Phys. Rev. **81**, 482 (1951); **81**, 627 (1951).
[2] F. Sauter, Ann. Physik **11**, 454 (1931).

SATURDAY AFTERNOON AT 2:00

Sanders Theatre

(E. C. KEMBLE presiding)

Invited Paper

WA1. Some Formal Developments in Quantum Mechanics. JULIAN SCHWINGER, *Harvard University.* (30 min.)

Theoretical Physics, Atomic and Molecular

WA2. Spin Interactions of Accelerated Nuclei in Molecules. NORMAN F. RAMSEY, *Harvard University.*—In the past theories[1] of the spin rotational magnetic interaction in molecules, it has been assumed that the magnetic field at the nucleus due to the rotation of the molecule arises solely from the circulatory currents of the other charges in the molecule. However, when account is taken of the acceleration of the nucleus, two additional terms must be added. One of these arises from the fact that associated with the acceleration there is an electric field and that a moving nuclear magnetic moment interacts with such a field. The other term is the Thomas precession which occurs for any moving and accelerated angular momentum. Two sources of the acceleration must be considered: one is the centripetal acceleration associated with the rotation and the other is the acceleration associated with zero point vibration. In the case of molecular hydrogen the latter is by far the most important. It has been calculated that the contribution of these effects to the spin-rotational interaction constants are 1170 cps for H_2 and 29 cps for D_2.

[1] G. C. Wick, Phys. Rev. **73**, 51 (1948).

WA3. Pressure Broadening by Electron Impacts.* B. KIVEL, *Yale University.*—The effects of quenching (Q) and nonquenching or broadening (B) electron collisions upon the emission line of a two state atom are studied. Use is made of a quantum-mechanical perturbation treatment by Bloom[1] and Margenau, which considers momentum transfer between a single electron and an emitting atom. If modification of the original line shape, $I\alpha(\gamma^2+\omega^2)^{-1}$, is small, then $I_Q \simeq I[1-2fIS_Q]$ and $I_B \simeq I[1-fIS_B(1-\omega^2/\gamma^2)]$, where $f=2nv\pi(\hbar/mv)^2/\gamma$, n=electron density, v=electron velocity, and S_Q, S_B are related to the atomic form factors. The quantity f is essentially the fraction of atoms hit. The quenching correction is everywhere negative, corresponding to fewer emitters. I_B is decreased only within the half-maximum, giving a redistribution corresponding to energy exchange between perturber and radiation. S_B/S_Q increases with the energy separation between the two atomic states. For hydrogen, $2p \rightarrow 1s$, with $n=10^{14}$ cm^{-1}, $v=e^2/5\hbar(\frac{1}{5}$ ev), $\gamma=6.25\times10^8$ sec^{-1}; $f=0.03$, $S_Q=0.05$, $S_B=2.8$, and broadening is dominant. Both electron effects are smaller by at least a factor 10 than Stark-broadening by ions at this density.

* Sponsored by the ONR and AEC.
[1] S. Bloom, dissertation, Yale University (1952).

WA4. Spectral Line Broadening by Electrons.* S. BLOOM, *R. C. A. Laboratories.*—Quantum radiation theory is employed to calculate the probability of emission arising from the joint perturbations of a radiation field and an electron upon the emitting atom. The smallness of the electron mass requires that its states be included in the calculation, the radiator and perturber being combined into a single system, closed except for radiation. To illustrate the method, we treat the simplified case in which the emittor and perturber have each only two states. When, in the four amplitude-growth equations, terms involving a summation over field-oscillator states are replaced by a natural decay constant γ, these equations permit an exact solution. The justification for this procedure rests upon the smallness of γ, compared to the atomic frequency ω_0. The resultant intensity formula exhibits the four resonances $\omega=\omega_0\pm a\pm b$ (where a and b are proportional to the two collision matrix elements) and shows that a two-state perturber distributes the intensity of the natural line with differing weights at the places corresponding to the statically perturbed energy levels. When the two atomic states are identically influenced by the perturbing electron, the intensity formula reduces to that for the natural line, in accord with the phase-integral as well as the statistical distribution of the classical-orbit treatments.

WA5. The Motion of Slow Electrons in Polar Crystals.* D. PINES AND F. LOW, *University of Illinois,* AND T. D. LEE AND C. N. YANG, *Institute for Advanced Study.*—A variational technique is developed to investigate the low-lying energy

levels of a conduction electron in a polar crystal. Because of the strong interaction between the electron and the longitudinal optical mode of the lattice vibrations, perturbation-theoretic methods are inapplicable. Our technique, which is closely related to the "intermediate coupling" variational method introduced by Tomonaga[1] and applied to this problem by Lee and Pines,[2] is shown to be equivalent to a simple canonical transformation. The use of this transformation enables us to obtain the wave functions and energy levels quite simply. These agree with the results of Lee and Pines[2] for these low-lying energy levels. Because the recoil of the electron introduces a correlation between the emission of successive virtual phonons by the electron, the Tomonaga approximation, in which this correlation is neglected, breaks down for very strong electron-phonon coupling. The validity of our approximation will be discussed.

* This work was supported in part by the Office of Ordnance Research.
[1] S. Tomonaga, Prog. Theoret. Phys. **2**, 6 (1947).
[2] T. D. Lee and D. Pines, Phys. Rev. **88** (to be published).

WA6. Some Remarks on the Pines-Bohm Theory of Many Particles with Long-Range Forces. GEORGE J. YEVICK, *Stevens Institute of Technology and University of Maryland.*—In a very interesting paper, Pines and Bohm[1] have presented the beginnings of a more detailed description of the organized behavior of many particles with long-range forces. We should like to point out some results which may aid in carrying over the theory into quantum mechanics. If one works in the Heisenberg representation, one can obtain an almost one-to-one correspondence between the classical equations of Pines and Bohm and the equations of motion of the quantum-mechanical operators, e.g., the collective coordinate q_k. From the equations of motion, one guesses a suitable Hamiltonian in q_k space in order to obtain the Schrodinger wave functions which are really what one seeks. The q_k do not commute; but for low wave numbers apparently only a slight error is made if one assumes they do. Knowing the wave functions in q_k space, one can transform back to the ordinary coordinate space to obtain the wave functions we seek. It is necessary, of course, to limit the number of degrees of freedom of q_k which will introduce some error in the assumed Hamiltonian as compared to the correct n-body Hamiltonian.

[1] D. Pines and D. Bohm, Phys. Rev. **85**, 338 (1952).

WA7. Adiabatic Treatment of Slow Atomic Collisions.* W. KOHN, *Carnegie Institute of Technology.*—When the relative velocity of two colliding atoms is small compared to the speed of the atomic electrons, the collision can be treated in the adiabatic approximation. The situation is particularly simple when the total internal energy of the two atoms is the same before and after the collision. The calculation of the cross section requires then only a knowledge of the electronic energy levels of the entire system as a function of the internuclear distance. The electron pick-up process $p+H \rightarrow H+p$ has been studied from this point of view for proton energies $\ll 25$ kev, and preliminary results for the cross section have been obtained.

* Supported in part by the OOR.

WA8. Effect of Boundary States on Free Electron Diamagnetism. FRANK HAM AND HARVEY BROOKS, *Harvard University.*—The WKB approximation is used to calculate the energy and magnetic moment of single electron states in a large cylindrical box with a uniform magnetic field parallel to the axis. The surface states are found to be strongly paramagnetic, whereas the bulk states exhibit the diamagnetic moment of the free electron. The sum of the single state moments weighted with the statistical probability of occupation gives the usual value[1] for the resultant moment of the system for sufficiently strong field strengths. Correction terms from surface states and from states whose orbits loop the origin are evaluated. Corrections to the oscillatory De Haas-Van Alphen terms are small provided the radius R of the box is large compared to the radius R_c of the orbit of a classical electron moving with energy equal to the Fermi energy ζ, but corrections to the Landau steady diamagnetism are large unless R is large compared to $(\zeta/\beta H)R_c$. The present discussion is valid for strong fields: $R > R_c$.

[1] D. Schoenberg, Proc. Roy. Soc. (London) **A170**, 341 (1939).

WA9. Spin-Dependent Couplings in a Many Electron System. W. J. CARR, JR., *Westinghouse Research Laboratories.*—It will be shown that the Dirac-Van Vleck model for a many-electron system is a good approximation, when non-orthogonality questions are properly considered, provided the overlap integrals are within reasonable bounds and provided the Heitler-London exchange integral is slightly modified so as to include in the two-body Hamiltonian the time average potential of all other charges in the system. This modification increases the probability that the exchange integral between electrons on neighboring atoms in a solid is negative. Three-body couplings leading to magnetic interactions through closed shell atoms will be discussed.

SATURDAY AFTERNOON AT 2:00

Geology Lecture Room

(E. C. POLLARD presiding)

Biophysics; High Polymer Physics; Liquids

X1. The Inactivation of Desoxyribonuclease by Particle Bombardment and by Heat. CYRIL L. SMITH,* *Yale University*† (introduced by E. C. Pollard).—Commercially obtainable desoxyribonuclease was evaporated from solution in thin layers on to a glass cover slip and bombarded with deuterons of maximum energy 3.7 Mev produced by the Yale cyclotron. The survival-dose curve is logarithmic. By varying the energy of the incident deuteron beam the ion density was varied from 2.25 to 5 primary ion pairs per 100A of enzyme, assuming the density to be 1.3. These measurements enable an inactivation cross section to be measured and this is approximately 4000A^2. The inactivation of the dry material has also been studied at various temperatures from 102°C to 180°C, and from these measurements the free energy of the molecule may be calculated. This enables the heat of activation ΔH and entropy ΔS to be computed: The values so obtained are, respectively, $\Delta H = 16 \times 10^3$ cal/mole and $\Delta S = -37$ cal/mole °K.

* Higgins Research Fellow, Yale University.
† Supported by the USAEC.

X2. The Quantum Yield for the Inactivation of Dry Chymotrypsin. RICHARD SETLOW, *Yale University.**—A knowledge of the wavelength dependence of the quantum yield for the inactivation of enzymes by ultraviolet light is

important for an understanding of the action spectra of viruses and micro-organisms and for the analysis of the effects of ionizing radiation on biological material. Thin samples of chymotrypsin in a vacuum were irradiated by monochromatic light obtained from a mercury arc and a water-prism monochromator. The enzymatic activity before and after irradiation was determined by the ability of the enzyme to digest casein. The activity remaining after irradiation decreases exponentially with the number of incident photons/cm², and hence, an inactivation cross section may be computed. The quantum yield, the ratio of inactivation to absorption cross section, has been found for 7 wavelengths between 2967A and 2300A. It rises from 0.008 at long wavelengths to 0.02 at 2300A. At 2537A the quantum yield decreases for irradiation at 90°K.

* Assisted in part by the AEC.

X3. Biological Determination of the Range of Low Voltage Electrons. MARGUERITE DAVIS,* *Yale University*† (introduced by E. C. Pollard).—An effort to determine the ranges of electrons from 100 to 2000 volts was made by the irradiation of biological material. A uniform layer of the enzyme, invertase, was spread on a coverslip, dried, and bombarded. Dose survival curves show a long trail off region indicating a limited range for the electrons less than the thickness of the sample used. The inactivation due to bombardment by large doses of electrons can be expressed in micrograms of invertase in a layer within the range of the electrons. By knowing the area over which the enzyme is spread, and assuming a density of 1.3, the fraction inactivated can be used to determine the range of the electron. Between 100 and 800 volts, the amount inactivated remains essentially the same, corresponding to a layer of enzyme between 70 and 90A. This probably is the thickness of one invertase molecule. Above 800 volts the range increases quite rapidly. This method gives a maximum range for the low voltage electrons facilitating the interpretation of data on the bombardment by low voltage electrons of other materials.

* Public Health Service Research Fellow.
† Assisted by the USAEC.

X4. Particle Size of Alpha-Amylase. JOHN JAGGER,* *Yale University*.†—The material investigated was a dextrinogenic (alpha) amylase from *B. subtilis*. Thin layers of the amylase were bombarded in the dry state by ionizing particles. The resultant inactivation was measured as loss of enzyme action on soluble starch substrate, the assay being based upon optical density of the starch-iodine complex. 2.75-Mev deuterons (producing one primary ionization per 50A) from the Yale cyclotron yielded an inactivation cross section of 1240A². 2.0-Mev electrons (producing one primary ionization per 4000A) from the Brookhaven Van der Graaff machine yielded an inactivation volume of 50 500A³. These data are compatible if the target is assumed to be a cylinder with diameter and height both equal to 40A and with a minimum molecular weight of 39 500. Such a shape is consistent with deuteron data taken over an ion density range of 2.1 to 6.5 primary ionizations per 100A. This minimum molecular weight compares with published values ranging from less than 45 000 to 60 000 for alpha-amylases from nonbacterial sources.

* AEC fellow.
† Assisted by the USAEC.

X5. Ionizing Radiation Evidence for Internal Structure in a Bacterial Virus. M. FRIEDMAN AND E. POLLARD, *Yale University*.—The laws of ability to infect the host bacterium *B-megatherium* by *M*-5 bacteriophage has been studied after deuteron and electron bombardment. In both cases a semilogarithmic survival curve is obtained. Since for deuterons the ionization is confined to narrow swaths of dense ionization distributed randomly in area the curve permits the calculation of a cross section. For electrons the ionization is random in volume and so yields a volume. The values found are 2.05×10^{-11} cm² and 4.4×10^{-18} cm³. These are not compatible with a spherical sensitive region but indicate a long thin sensitive structure of between 3500 and 7000A in length and 50 to 25A in diameter. This long thin structure may be partly in the tail and partly coiled inside the head of the virus.

X6. The Ultraviolet Action Spectrum of a Bacillus Megatherium Bacteriophage.* R. FRANKLIN, M. FRIEDMAN, AND R. SETLOW, *Yale University*.—Dry *M*-5 bacterial virus was irradiated in vacuum at room temperature with monochromatic ultraviolet light. The relative affectiveness of the radiation for inactivation of the virus has been determined in the wavelength region 2300–3000A. The data indicate that photons absorbed in both the protein and nucleic acid components lead to inactivation. A comparison with previous studies[1] on *T*-1 will be made.

* Assisted by the ONR.
[1] D. J. Fluke and E. C. Pollard, Science **110**, 274 (1949).

X7. Inactivation of Dysentery Toxin with Ionizing Radiation. D. L. CASPAR AND C. R. WOESE, *Yale University*.*—The bombardment of enzyme molecules with deuterons and electrons has shown that a primary ionization anywhere in a large fraction of the molecule will inactivate it. It is of interest to see if this technique can be applied to other types of biologically active material. Dysentery toxin has been investigated since its chemical composition and size have not been established. The material was irradiated with deuterons and electrons, and the residual toxicity was determined by mouse assay. The exponential inactivation curves give a target cross section and target volume corresponding to a molecular weight of about 11 000 for the radiation sensitive toxic unit. This technique indicates that the toxic unit of dysentery is organized in a macromolecule of a size comparable to that of many biologically active proteins.

* Assisted by the USAEC.

X8. The Scattering of Light from Polymer Films.* RICHARD S. STEIN AND JOHN J. KEANE, *University of Massachusetts*.—The measurement of the scattering of light from solid polymers is a means for studying their structure. Films are the most convenient form for obtaining polymers subjected to such treatment on temperature variation, mechanical deformation, and orientation. In measuring scattering from films, it is necessary to correct the observed scattered intensity for (a) refraction at film interfaces, (b) reflection, (c) secondary scattering, and (d) polarization. The necessary correction factors are described in this paper. Measurements of the scattering from polyethylene films as a function of angle of both the film and photometer and of the thickness of the film are described, and the application of the correction factors to these measurements is illustrated. A device is described for studying the light scattering from films at elevated temperatures.

* This work is supported in part by a contract with the ONR.

X9. The Statistics of Stiff Chains. J. J. HERMANS, *University of Groningen*, AND ROBERT ULLMAN, *Polytechnic Institute of Brooklyn*.* This paper deals with the statistical properties of worm-like chains where the stiffness of the chain is specifically taken into account by introducing the directional correlation between successive portions of the chain. The treatment makes use of the theory of Brownian motion, and in this connection the methods introduced by Kramers are applied. For a chain in three-space a differential equation for the probability that a point l units along the chain is at a distance r from the beginning of the chain and pointing in a given direction $\omega(\alpha, \beta, \gamma)$ is derived. A solution of this equation has not been obtained, but average values of the form $\langle r^{2k} \rangle_{Av}$ have been calculated. This model of a chain has

applications in the theories of high polymer solutions and should also be applicable to certain problems concerned with the scattering of nuclear particles.

* This work was done while Robert Ullman was a Fulbright fellow at the University of Gronigen.

X10. Methods for Advancing the Subject of Liquid. GEORGE ANTONOFF.—Valuable information is derived from the theory of surface tension, which led to the definite concept of molecular status of liquids.[1] Physical properties (densities, vapor pressure, etc.) are known with such accuracy that the experimental errors can not be seen on the graph: They reveal discontinuities contrary to classical views, which is in accord with the above theory. Other methods which came into fashion in the last decades are disappointing. X-ray method did not give the results expected. Quantum-mechanical treatment has shown itself useless. The statistical-mechanical methods led to clumsy relations in poor agreement with experimental evidence. No theory which ignores kinks can lead to a real progress. Thus, formulas of Andrade and others fail, because agreement is only possible for the range between two kinks.

[1] J. Phys. Chem. **36**, 2406 (1932).

X11. Interpolation of Vapor Pressures. PAYMOND MADRAZO, JR., AND GEORGE ANTONOFF.—In the paper by L. E. Smith, F. G. Keyes, and H. T. Gerry[1] values of direct experiments are given without smoothing. Three points between two kinks are needed to construct the equation $p=A-Bt+Ct^2$, suitable for exact interpolation. The authors mentioned interpolated less accurately, their values differing from ours within 0.1 percent. The values of RP 1229, also smoothed, differ from ours to within 0.1 percent. Both are good enough for demonstration of kinks, as is other modern data. Regnault's values are not considered, because his temperature standards are not up to date. Thus, kinks have a real existence and considerable theoretical significance.

[1] Smith, Keyes, and Gerry, Proc. Am. Acad. Arts Sci. **69** (1934).

SATURDAY AFTERNOON AT 2:00

Allston Burr, A

(R. L. SPROULL presiding)

Electromagnetic and Electron Physics

Y1. Diffraction Field of a Circular Aperture. G. A. WOONTON, *McGill University*.—The following equation which is of a form given by Stratton, but which has been modified to bring it into agreement with five known *a priori* theoretical and experimental conditions has been found to predict the diffraction field in and near circular apertures several wavelengths in diameter:

$$\frac{V(x',y',z')}{d}=\frac{1}{4\pi}\int_{S_0}\left\{E_i\frac{\partial\psi}{\partial n}-\psi\frac{\partial E_i}{\partial n}\right\}da$$
$$+\frac{1}{4\pi}\left(\frac{\mu}{\epsilon}\right)^{\frac{1}{2}}\oint_C(\boldsymbol{\varrho}_1\cdot\mathbf{r}_1)\psi\mathbf{H}_i\cdot d\mathbf{S}-\frac{1}{4\pi}\oint_C\psi(\mathbf{n}_1\times\mathbf{r}_1\cdot\boldsymbol{\varrho}_1)\mathbf{E}_i\cdot d\mathbf{S}.$$

In this equation $V(x', y', z')$ is the emf generated at the terminals of a short dipole of length d. The dipole is orientated with its long axis (this direction is given by the unit vector $\boldsymbol{\varrho}_1$) parallel to the incident electric field E_i and perpendicular to the incident magnetic field H_i. The unit vector $\mathbf{n}_1$ is normal to the plane diffraction screen and points into the region containing $P(x', y', z')$, while $\mathbf{r}_1$ is a unit vector pointing from (x', y', z') to an aperture point (x, y, z). The symbol ψ denotes the Green's function $\exp[-jkr]/r$. The surface integral is to be taken only over the circular opening in the screen and the contour integrals around the rim.

Y2. Generalization of Kirchhoff's Theorem to Electromagnetic Fields. H. E. J. NEUGEBAUER, *McGill University*.—Kirchhoff's formula cannot be used to predict finer details of diffraction patterns in the near field because it does not satisfy Maxwell's equations. Rigorous solutions are known for very few cases only and are hard to evaluate. Describing the field by the Hertzian vector $\mathbf{\Pi}$ and using, as first approximation, the field $\mathbf{\Pi}_1$ predicted by geometrical optics, we can compute a correction term $\mathbf{u}$ so that $\mathbf{\Pi}=\mathbf{\Pi}_1+\mathbf{u}$ satisfies Maxwell's equations everywhere including those mathematical surfaces, C, in space where $\mathbf{\Pi}_1$ exhibits a jump. The term $\mathbf{u}$ is represented by an integral over C that can be reduced to a contour integral or transformed to an integral over the aperture being similar to Kirchhoff's. The field $\mathbf{E}$ and $\mathbf{H}$, derived from $\mathbf{\Pi}$ matches experimental results in the case of a plane wave incident on a plane screen with a circular hole. The method predicts the field on both sides of the screen. To a certain degree properties of the screen (absorption, thickness) can be accounted for. The surface integral over C can be interpreted by a physical picture opening the way to still better approximations that satisfy the boundary conditions at the screen.

Y3. Diffraction of Electromagnetic Waves by an Aperture in an Infinite Screen. G. BEKEFI, *McGill University*.—Microwave diffraction measurements made within and in the neighborhood of large circular apertures cannot be explained on the basis of either the Kirchhoff or the vector-Huygens theories of Stratton and Chu. An exact evaluation is not available at the present time. It is, however, possible to predict the measurements by an approximate method by constructing the electromagnetic field from a single component of the Hertz vector $\mathbf{\Pi}$, thereby reducing the solution to an inhomogeneous scalar boundary-value problem. That component Π_a is chosen which lies in the direction of the incident electric field. For very large apertures the problem can be further simplified and the Hertz vector at any point in the half-space away from the source can be calculated from

$$\Pi_a=-\frac{1}{2\pi}\int f_a\frac{\exp(-jkr)}{r}dS,$$

where the integration extends over the aperture area; f_a is the normal derivative of the Hertz vector associated with the incident wave and r is the distance from the field point to an element δS.

Y4. Guided Surface Waves on Lossy Structures. FRANCIS J. ZUCKER, *Air Force Cambridge Research Center* (introduced by R. C. Spencer).—The general theory of surface waves has been developed to the point where it is possible to treat lossy structures and to throw new light, incidentally, on the old controversy regarding the existence of the Zenneck wave. Starting with two arbitrary media adjoining a cylindrical or plane interface, it is shown that the total electromagnetic field can be written as the sum of residues and branch cut contribu-

tions, representing energy-carrying surface wave modes and the accompanying radiation field, respectively. The location of the poles and branch points in the plane of the complex propagation constant depends on the geometry of the interface and the electromagnetic properties of the adjoining media. This location in turn controls the existence and relative importance of the various surface wave modes. Special cases included in this approach, in addition to the Zenneck wave, are the following: wave guide with lossy dielectric, wave guide with lossy walls, lossy dielectric rod, helix with ferrite core, and lossy single wire (Sommerfeld wave). Experiments are cited which verify much of this theoretical work.

Y5. Transition from Classical to Quantum Interaction between Electron and High Frequency Field. I. R. SENITZKY, *Signal Corps Engineering Laboratories.*—In analyzing transition from classical to quantum interaction between electron and electromagnetic radiation field as frequency increases, initial state of system should be taken as wave packet in position and momentum coordinates for electron, and wave packet in vector potential and electric intensity coordinates for field. For an electron well-localized in position and momentum space traversing resonant cavity of macroscopic dimensions, quantum effect manifests itself in random dispersion about classical value of electron velocity increment, producing noise current in an electron beam. If oscillating mode of unperturbed field in cavity is represented by oscillating wave packet of constant Gaussian shape, the mean square deviation from expectation value of the velocity increment, for interaction which produces small perturbation, is

$$\langle(\Delta v)^2\rangle - \langle\Delta v\rangle^2 \simeq 2\pi(e/m)^2 \sum_k \hbar\omega_k \left| \int_{\tau_1}^{\tau_2} u_k(vt) e^{i\omega_k t} dt \right|^2.$$

v is mean entrance velocity, $u_k(r)$ is normalized spatial dependence of vector potential for kth mode, τ_1 and τ_2 are mean entrance and exit times. Summation is over all cavity modes, including those of zero energy. Significance of result is discussed.

Y6. Transverse Motion of an Electron in a Constant Wave Speed Section of a Linear Accelerator. IRA JACOBS AND E. S. AKELEY, *Purdue University.*—The relativistic differential equations of motion of an electron in a linear accelerator are considered. The field components are expanded in powers of distance from the axis r, and terms in r and $\dot{r}$ of order two higher than the lowest order terms are neglected. Two first integrals together with the equation of motion for the r coordinate, give a second-order nonlinear differential equation for r as a function of the phase of the electron with respect to the peak of the accelerating electric field. A choice of a particular dc magnetic focusing field allows this equation to be integrated twice. Utilizing earlier results giving the dependence of phase on the longitudinal distance z, r as a function of z is plotted. The need for a focusing field is indicated, and it is shown that the particular field chosen has the advantage that with it, the electron will oscillate between known fixed limits of r. The necessity of shielding the electron emitter from the focusing field is shown, and an indication of the magnitude of the field and the length of the accelerator for which it should be used, is given for the Purdue accelerator.

Y7. Study of an Electron Gun. JOHN W. COLEMAN, *National Bureau of Standards* (presented by L. Marton).—An electron gun producing a real image beyond the accelerating electrode aperture was investigated. A resistance-network type analog computer for axially symmetric fields was used for this study. The gun is based on a design by Steigerwald[1] including a filament-housing cone to shape the field near the cathode, and produces a beam of nearly parallel rays. Five parameters were studied: (1) cone angle; (2) axial distance between cone aperture and bias electrode; (3) bias electrode aperture; (4) axial distance between bias electrode and accelerating electrode; and (5) accelerating electrode aperture. Fields were mapped for different configurations and trajectories were drawn by the parabola method. Cross-over points were extrapolated and errors calculated. Results showed that with all of the cone angles studied, (4) and (5) being constant, there are values for (2) and (3) which produce any desired degree of approximation to parallelism. The best results have been obtained with a 90-degree cone.

[1] K. H. Steigerwald, Optik **5**, 469 (1949).

Y8. Excitation of Light by Hydrogen Ions.* ERNEST J. DIETERICH, *Harvard University.*—In order to study excitation processes in the aurora and check calculations for excitation by protons in helium,[1] apparatus has been constructed for observing the light produced when protons of a few thousand volts' energy pass through gases at low pressure. In previous attempts to observe this light either the light has been masked by the stronger light excited by neutral atoms, or the nature of the ion has been uncertain. In the present apparatus hydrogen ions from a radiofrequency ion source[2] are magnetically separated in high vacuum. Protons, H_2^+, or H_3^+ can be focused on a $\frac{1}{16}$-inch aperture 13 inches from the source. Neutrals from the source may be eliminated by a baffle. The beam of 10μa passes into the observation chamber containing helium and provided with a pair of deflecting plates to separate ions from the few neutrals. The light is observed through a window with a fast spectrograph. Pressures are maintained by differential pumping. The results presented will illustrate the operation of the apparatus.

* Assisted by the ONR.
[1] Massey and Smith, Proc. Roy. Soc. (London) **A142**, 142 (1933).
[2] Moak, Reese, and Good, Nucleonics, p. 18 (September, 1951).

Y9. Relative Ionization Probability of Helium near Threshold. T. KJELDAAS, JR., W. M. HICKAM, AND R. E. FOX, *Westinghouse Research Laboratories.*—The recently reported[1] retarding potential difference method for observing in a mass spectrometer ionization produced by the impact of essentially monoenergetic electrons has been used to study the relative ionization probability curve for helium in the vicinity of threshold. Earlier studies of krypton and xenon[2] showed that the observed structure in their ionization probability curves could best be interpreted by assuming a linear law for the ionization to each of the possible ground states of the ions. Since a singly charged helium ion has a single ground state with the first excited state some forty volts removed, the opportunity is afforded for investigating the threshold law over a wider energy range. For an energy range of at least 8 ev above the ionization potential, no deviation from linearity is detected. The limit of detectability for such deviations and tests of the linearity of the threshold law for certain other gases will be discussed.

[1] Fox, Hickam, Kjeldaas, and Grove, Phys. Rev. **84**, 859 (1951).
[2] Fox, Hickam, and Kjeldaas, Phys. Rev. (to be published).

Y10. Ionization Probability near Threshold for the Formation of Xe^{++}, Kr^{++}, A^{++}, and Ne^{++}. W. M. HICKAM, R. E. FOX, AND T. KJELDAAS, JR., *Westinghouse Research Laboratories.*—Using a method[1] described earlier for observing ions in the mass spectrometer formed by essentially monoenergetic electrons of known energy, the relative ionization probability curves near threshold for Xe^{++}, Kr^{++}, A^{++}, and Ne^{++} are obtained. These ions possess four states ($^3P_1$, $^3P_0$, $^1D_2$, and $^1S_0$) lying within seven electron volts of the $^3P_2$ ground state. The curves exhibit structure which can be correlated with the known location of the above levels when the linear threshold law[2,3] is assumed to hold for each of these levels. Certain details in the curves indicate the presence of auto-ionization.[3] The results offer an explanation for the unusually large amount of

tailing in the A^{++} ionization probability curve obtained by Stevenson and Hipple.[4]

[1] Fox, Hickam, Kjeldaas, and Grove, Phys. Rev. **84**, 859 (1951).
[2] Fox, Hickam, and Kjeldaas, Phys. Rev. (to be published).
[3] See Y9, preceding abstract.
[4] Stevenson and Hipple, Phys. Rev. **62**, 237 (1942).

Y11. Magnetically Self-Focusing Discharges. WILLARD H. BENNETT, *Naval Research Laboratory.*—The large dc currents found by Thoneman, Cowhig, and Davenport[1,2] to arise in discharges in gases at low pressures in a torus-shaped tube excited with purely sinusoidal ac currents in a coil wrapped around the outside of the torus are to be expected from the theory[3] of magnetically self-focusing streams. Whenever there is a mixture of the two electron currents in the two directions in the discharge, that electron current which is the greater will magnetically repel the electrons moving in the reverse direction and systematically eject them from the stream. Thus it is only the majority current which is self-focusing, and its effectiveness in ejecting the minority current becomes greater as its excess over the minority current increases. Other recently reported effects[4,5] are similarly anticipated by the theory.

[1] Thoneman, Cowhig, and Davenport, Nature **169**, 34 (1952).
[2] P. C. Thoneman and W. T. Cowhig, Proc. Phys. Soc. (London) **64**, 345 and 618 (1951).
[3] W. H. Bennett, Phys. Rev. **45**, 890 (1934).
[4] Bostick, Levine, and Coombes, Paper E-8, Gaseous Electronics Conference, Princeton, New Jersey, September 6, 1952.
[5] S. W. Cousins and A. A. Ware, Proc. Phys. Soc. (London) **64**, 159 (1951).

Y12. Constriction of High Power Discharges by an Intense Magnetic Field. K. S. W. CHAMPION,* *University of Birmingham, England* (introduced by S. C. Brown).—A thorough investigation has been made of the claim of Cummings and Tonks[1] that a uniform longitudinal magnetic field does not constrict an arc. Discharges of about 100 amps in hydrogen were used and magnetic fields ranging in strength from zero to 23 000 gauss. Because of the very high power dissipation and the resultant cooling and gas clean-up problems both the discharge and magnetic field were pulsed. The length of the discharge pulse was 2 msec, and this was shown to be completely adequate for steady state conditions to be attained. It was found that even a weak magnetic field tended to constrict an arc and that this was always observed except (as in Cummings and Tonks experiment) when it was obscured by boundary conditions. Further, it was found that most of the change was produced by fields of, say, 2000 gauss and that the diameter and positive column gradient tended to limits with very strong fields. This is in agreement with theory[2] which also predicts limiting values for the particle temperatures.

* Now at M.I.T.
[1] C. S. Cummings and L. Tonks, Phys. **Rev. 59**, 514 (1941).
[2] K. S. W. Champion, Proc. Phys. Soc. (London) **B65**, 329 and 345 (1952).

Y13. The Particular Case of Free Electron Emission in the Atmosphere. OLEG YADOFF, *Columbia University.*—It is a matter of common knowledge that any conducting body placed in the interior of a closed system cannot be electrically influenced from the surrounding medium. Our recent experiments show that in certain conditions we obtain an electric charge in conducting bodies placed in the interior of such a closed system. If, for example, we place in the center of a closed cylinder a thin wire, and if we connect this cylinder with one of the poles of an electrostatic source, then in the interior of the closed cylinder there is created a fairly strong electric field which results in an emission of free electrons from the wire. It is understood that such an internal conductor must be well isolated from the closed system. An electroscope placed in the interior of the cylinder and connected to one end of the internal wire registers the presence of these electrons. If the wire is approached from the exterior with a conductor, then we obtain, first, a spark of several millimeters, and second, upon their absolute contact, a constant flow of electrons.

SATURDAY AFTERNOON AT 2:00

Allston Burr, B

(M. S. GOLDHABER presiding)

Radioactive Nuclei, II; Fission

Z1. Gamma-Radiation from Zr^{95} and Nb^{95}.* E. R. ZUCKER,† C. E. MANDEVILLE, E. SHAPIRO,‡ R. I. MENDENHALL, AND G. L. CONKLIN,§ *Bartol Research Foundation.*—Employing lead absorption, coincidence counting techniques, and scintillation spectrometry, it has been shown that each beta-ray of Nb^{95} is followed by a gamma-ray of energy 0.76 ± 0.02 Mev, and that most of the beta-rays of the parent element, Zr^{95}, are followed by a single gamma-ray at 0.73 ± 0.02 Mev. Most of the disintegrations of Zr^{95} may be characterized by $d_{5/2}\rightarrow g_{7/2}\rightarrow g_{9/2}$.

* Assisted by the joint program of the ONR and AEC.
† Frankford Arsenal.
‡ At present at Tracerlab, Inc., Boston, Massachusetts.
§ At present at Wyeth, Inc., Philadelphia, Pennsylvania.

Z2. The β-Spectrum of Cs^{135}. L. LIDOFSKY, E. ALPEROVITCH, AND C. S. WU, *Columbia University.*—The long-lived radioactive Cs^{135} ($t_{\frac{1}{2}}\sim2-5\times10^6$y) is the daughter product of Xe^{135} which can be produced in large amounts in the fission process. The transition involved in the β-decay of Cs^{135} is from $g^{7/2}$ to $d^{3/2}$; therefore, it is a $\Delta I=2$, (no) transition. The shape of the β-spectrum from this type of parity unfavored second forbidden transition has special theoretical interest, as it may narrow the possible choices of the linear combination of interactions. To prepare a few hundredths of μc of Cs^{135} requires the collection of about 100 curies of Xe^{135}. We are most grateful to Dr. Sugarman of Argonne National Laboratory, who generously put at our disposal his only Cs^{135} sample. The sample contained about 10 μg of Cs^{135} with about 0.016 μc activity but also contained several hundred mg of impurities from glass and nitric acid. The silver-cobaltinitric method was finally adopted for purification after a long series of trial runs. The final source retained around 0.01 μc of activity and contained less than 100 μg of solids. The spectrum yields an upper energy of 205 kev, is forbidden, and slightly concave upwards. Attempts have been made to interpret the spectrum from a single interaction or a linear combination of interactions. A comparison among the spectra of the various known $\Delta I=2$, (no) transitions will also be presented.

Z3. The Disintegration of W^{187}: Evidence for a Slow $E1$ Transition. A. W. SUNYAR, *Brookhaven National Laboratory.*—Transitions between states of Re^{187} have been studied by $\gamma-\gamma$ coincidence techniques, imposing energy selection on both scintillation counters. Conversion studies have been made and gamma-ray multipolarities obtained. The 0.5 μsec lifetime is determined by a 72-kev $E1$ transition, which is followed by a 134-kev transition ($M1$) to the ground state.

The intensity of the unconverted 206-kev cross-over γ-ray is $<1/30$ of that of the unconverted 134-kev γ-ray. The 0.5 μsec state is populated by a 480-kev ($E2$) gamma-ray. A cross-over γ-ray of 552 kev ($E1$) is in prompt coincidence with the 134-kev gamma-ray, as is a gamma-ray of $\sim$780 kev. A low energy ($\sim$380 kev) and low intensity ($\sim$5 percent) beta-group is required. The intense 686-kev γ-ray is found weakly in coincidence with K x-rays showing some feeding from higher energy states. Comparison of electron intensities of other workers, together with our measured γ-ray intensity ratios, implies that the 686-kev γ-ray is $E1$. The states of odd parity found contradict the single particle model and suggest coupling of several protons in $h_{11/2}$ orbits to other particles or to the core to form excited states of low spin. The long lifetime for the 72-kev $E1$ transition may be connected with the complexity of the state.

* Under the auspices of the AEC.

Z4. Radiations from RaD and RaE. C. S. Wu, F. Boehm, and E. Nagel, *Columbia University.*—The electron and gamma-spectra from RaD and RaE have been thoroughly investigated. Neither internal conversion electrons nor nuclear gamma-radiations were found in RaE. A faint K x-ray ($\sim$80 kev) of the order of 10^{-4}/disintegration due to the ionization effect was observed in RaE. The gamma-radiation from RaD was investigated with both krypton and argon proportional counters with brass and aluminum cathode.* The L_α, L_β, and L_γ radiations of Bi were observed and identified with critical absorber. The intensity ratios of L_α:L_β:L_γ are 1:1:0.3. The previously reported 7.8 kev ($\sim$10 percent) line was not found but could be strongly excited by copper backing. The weak 23-kev line may be present but the intensity is less than 1×10^{-3} per disintegration. The conversion electrons of RaD were investigated with a 180° β-spectrometer with a resolution $<$0.8 percent and a counter window of $\sim$6 μg/cm^2. The L_I, L_{II}, and L_{III} conversion lines of 46.4-kev line were resolved. The ratios of L_I:L_{II}:L_{III}:M are 1:0.073:0.014:20. No other lines were observed. The upper limit of the intensity of the reported lines at 42 kev, 37 kev, and 23 kev must be less than 0.5 percent of disintegration if the same conversion coefficient are assumed. The amount of unconverted 46.4-kev γ-radiation and the conversion coefficients were measured and will be discussed.

* We are indebted to Mr. M. McKeown of Brookhaven National Laboratory for letting us use his Al cathode counter for this check.

Z5. Alpha-Gamma Angular Correlation in ThC.† J. Horton and R. Sherr, *Princeton University.*—By the method of angular correlation, we have approximately determined the angular momentum carried off by the two most energetic alpha-particle groups in the ThCC″ transition. A 6-Mev alpha-particle and a 40-kev gamma-ray following it were detected by two NaI(Tl) scintillation counters. Differential pulse-height selection was made in both channels. Coincidence measurements at various angles were consistent with the correlation function $1+A\cos^2\theta$ predicted from the magnetic dipole character of the gamma-radiation. The ratio (coincidences at 90°)/(coincidences at 180°) is 1.298, with a statistical error of 0.011 and an uncertainty in the various corrections of 0.015. Using the above facts, the parity selection rule on alpha-decay, and the known spectral shape of the beta-transition ThCC′, one can establish the spin of ThC to be 1. Further analysis shows that if there is little electric quadrupole radiation the only spin assignments not ruled out by our experiment and by the character of the beta-decay of ThC″ are 1–3–4 and 1–4–5. Thus, values of angular momenta for the less energetic alpha-group lie between 2 and 5, and for the most energetic between 4 and 6.

† This work was supported by the AEC and the Higgins Scientific Trust Fund.

Z6. Gamma-Ray Spectrum of Ionium.† F. Rasetti and E. C. Booth, *Johns Hopkins University.*—Previous studies of the gamma-ray spectrum of ionium (Th^{230}) were performed by means of absorption measurements.[1–3] The existence of a 70-kev line was well ascertained, but no accurate data were available for the weak lines of higher energies. We investigated the radiations emitted by sources of the order of several microcuries supplied by the Argonne National Laboratory. An NaI(Tl) scintillation spectrometer was used. The spectrum was found to consist of three lines of energies 70 ± 2, 145 ± 3, and 235 ± 5 kev and intensities of 10^{-2}, 2.10^{-3}, and about 10^{-4} per distintegration, respectively. These data are in remarkably good agreement with the absorption measurements of Curie,[2] but seem incompatible with the levels of Ra^{226} deduced by Rosenblum, Valadares, and Vial (reported by Curie[2]) from their determination of the energies of the alpha-groups of Th^{230}. More accurate measurements are in progress, and a study of alpha-gamma and gamma-gamma coincidences is planned.

† Work supported by the AEC.
[1] A. G. Ward, Proc. Cambridge Phil. Soc. **35**, 322 (1939).
[2] I. Curie, J. phys. et radium **10**, 381 (1949).
[3] M. Riou, J. phys. et radium **11**, 185 (1950).

Z7. Angular Distribution of Fragments from Neutron-Induced Fission. W. C. Dickinson and J. E. Brolley, Jr., *Los Alamos Scientific Laboratory.*—A parallel-plate ionization chamber has been used to measure the distribution of fission fragments from U^{233} and U^{235} in the angular range from 0° to 90° with respect to an incident beam of thermal neutrons and of 14-Mev neutrons. Thin foils of the fissionable materials were placed on the back of the negative high voltage electrode which was honeycombed with 0.04-inch diameter holes to serve as a collimator for the fission fragments. These holes were drilled at 45° to the normal in order that the experimental geometry would be identical for the 0° and 90° angular settings. For thermal neutrons no anisotropy was observed. For 14-Mev neutrons the ratios of fission fragment intensities at 0° to those at 90° (in the center-of-mass system) were determined to be 1.32 ± 0.11 and 1.27 ± 0.17 for U^{233} and U^{235}, respectively. In comparison the 0° to 90° intensity ratios, counting only the light fission fragments, were determined to be 1.41 ± 0.10 and 1.41 ± 0.14, respectively. (Ninety-five percent confidence intervals are attached to all values.) This would indicate that there is a slight excess of light over heavy fragments emitted in the forward direction.

Z8. The Response of NaI(Tl), KI(Tl), and Stilbene Phosphors to Fission Fragments. J. C. D. Milton and J. S. Fraser, *Chalk River Laboratory.*—The scintillations produced in NaI(Tl), KI(Tl), and stilbene by fragments from the slow neutron fission of U^{233} were observed with a 5819 photomultiplier. Care was taken to minimize surface effects particularly with NaI. The inorganic phosphors resolved the familiar double peaked fission spectrum, but stilbene did not. In all cases the fission fragment pulses were larger than the 4.8-Mev alpha-pulses, the ratio being (high peak:low peak:alpha) 2.1:1.6:1 for NaI, 3.5:2.3:1 for KI, $\sim$2:1 for stilbene. The relative alpha pulse heights NaI:KI:stilbene were 17.8:3.8:1. It was shown by measuring the energy of the paired fragment in an ionization chamber that the light fragment group produced the larger pulses. The relation between pulse height and residual range was measured by slowing down the fragments from U^{235} in argon before they entered a KI phosphor. It was found that the specific fluoroscence is a rapidly increasing function of the rate of energy loss. If the results are fitted

by a formula of the type given by Chou[1] the coefficient of $(dE/dx)^2$ is negative.

[1] C. N. Chou, Phys. Rev. **87**, 904 (1952).

Z9. The Distribution of Prompt Neutron Emission Probability for the Fission Fragments of U^{233}. J. S. FRASER AND J. C. D. MILTON, *Chalk River Laboratory.*—The kinetic energies of both members of pairs of fragments occurring in the slow neutron fission of U^{233} were measured in a double back-to-back grid ionization chamber. The two pulse heights were recorded only when in coincidence with a prompt fast neutron detected in either one of two high pressure methane ionization chambers situated on opposite sides of the fission chamber. Pulse lengthening peak voltmeter circuits were used to record the pulse heights on two synchronized recording milliammeters. The neutron emitting fragment was identified by recording on the sides of the charts which neutron counter was operated. About 20 000 such events were examined. For comparison the pulse heights of about 20 000 coincident fragment pairs were recorded without reference to neutron emission. Some results deduced from the data are (1) a strong correlation of the neutron emission probability of the fragments with the mass ratio, emission from the light fragment predominating at low mass ratios and emission from the heavy fragment at high mass ratios; (2) a little correlation of this probability with the total kinetic energy for a given mass ratio; and (3) an essentially constant total neutron emission probability for all fission modes as defined by the fragment kinetic energies.

Z10. Inelastic Collision Cross Sections for Fission Spectrum Neutrons. R. E. CARTER AND J. R. BEYSTER, *Los Alamos Scientific Laboratory.*—Neutron transmissions were determined by surrounding various threshold detectors with spherical shells of the elements listed below. Cross sections were calculated from the sphere transmissions using a method proposed by H. A. Bethe. This analysis and the experimental procedures will be discussed. Except where noted, rms errors in cross section are less than 10 percent (see Table I).

TABLE I.

Element	Np^{237} Detector	U^{238} Detector	$Al^{27}(n,p)Mg^{27}$ Detector
Al	0.14 ±0.04 barns	0.40 barns	0.73 barns
Fe	0.274 ±0.040	0.73	1.30
Ni	0.296 ±0.040	0.751	1.43
Cu	0.32	0.95	1.56
Zn	0.324 ±0.040	0.995	
Zr			1.70
Ag	0.86	1.67	2.03
Cd	0.67	1.54	2.08
Sn	0.38 ±0.050	1.15	2.07
W	1.09	2.18	2.75
Au	1.01	2.06	2.68
Pb	0.25 ±0.07	0.745	2.24
Bi	0.20 ±0.05	0.743	2.33

Z11. Fission of Uranium with 16-Mev X-Rays.* HAROLD G. RICHTER† AND CHARLES D. CORYELL, *M.I.T.*—The dependence of fission yield on mass number has been studied for the fission of natural uranium (U^{238}) with x-rays of 16-Mev maximum energy from the linear accelerator.[1] The following fission products were studied: $Br^{82,84}$, $Sr^{89,91,92}$, Y^{93}, Zr^{97}, Mo^{99}, Ru^{105}, $Pd^{109,112}$, $Ag^{113,115}$, Cd^{117}, Te^{132}, $I^{131,133}$, $Ba^{139,140}$, and Ce^{143}. Pre-existing chemical procedures[2] were tested and some modifications made for better suitability in quantitative isolation of the low activities available. Conditions of counting were controlled to permit the calculation of absolute disintegration rates. Fission yields were determined relative to 6.0 percent for 85m Ba^{139}. Precision of the values is about ±10 percent. The yield-mass curve exhibits the familiar double-humped shape, rising from about 0.3 percent at mass 83 to a maximum of about 6.2 percent at mass 97. The minimum is 0.05 percent at mass 117, and the heavy hump maximum is 6.2 percent at mass 138. Fission yields lying above a formal smooth curve were observed for 77*h* Te^{132} (5.8 percent) and 22.4*h* I^{133} (7.1 percent).

* This work was supported in part by the USAEC.
† Department of Chemistry, University of Oregon, Eugene, Oregon.
[1] P. Demos, M.I.T.-L.N.S.E. Technical Report No. 50, May, 1950.
[2] C. D. Coryell and N. Sugarman, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1951), Book 3, Part VI.

SUPPLEMENTARY PROGRAMME

SP1. Derivation of the Gauge Condition in the New Electrodynamics. M. AVRAMY MELVIN, *Florida State University.**—As is well known, extremalization of the traditional (Schwarzschild) action integral under fixed end-times yields not only the Maxwell equations for the field generated by a given current but also, as Born showed, the equations of motion for a charged particle in a given field. It can be demonstrated that the gauge restricting condition in the "new classical electrodynamics"[1] follows directly from extremalization of the same action function if, in making the comparison variations in the world-line of the particle, *one admits also free variations of the world-line at the end proper-times.* Thus to the field-law and motion-law consequences of extremalizing the action integral we may now add, under the wider variational conditions, the gauge condition of Dirac. In the terminology of the calculus of variations, it is the "natural boundary condition" for the classical electrodynamics of charged particles. One may heuristically extend this *"Free End-Condition Variational Principle"* to other relativistic field-particle theories.

* To be given at the end of Session JA if the chairman rules that time permits.
[1] P. A. M. Dirac, Proc. Roy. Soc. (London) **A209**, 291 (1951); **212**, 330 (1952).

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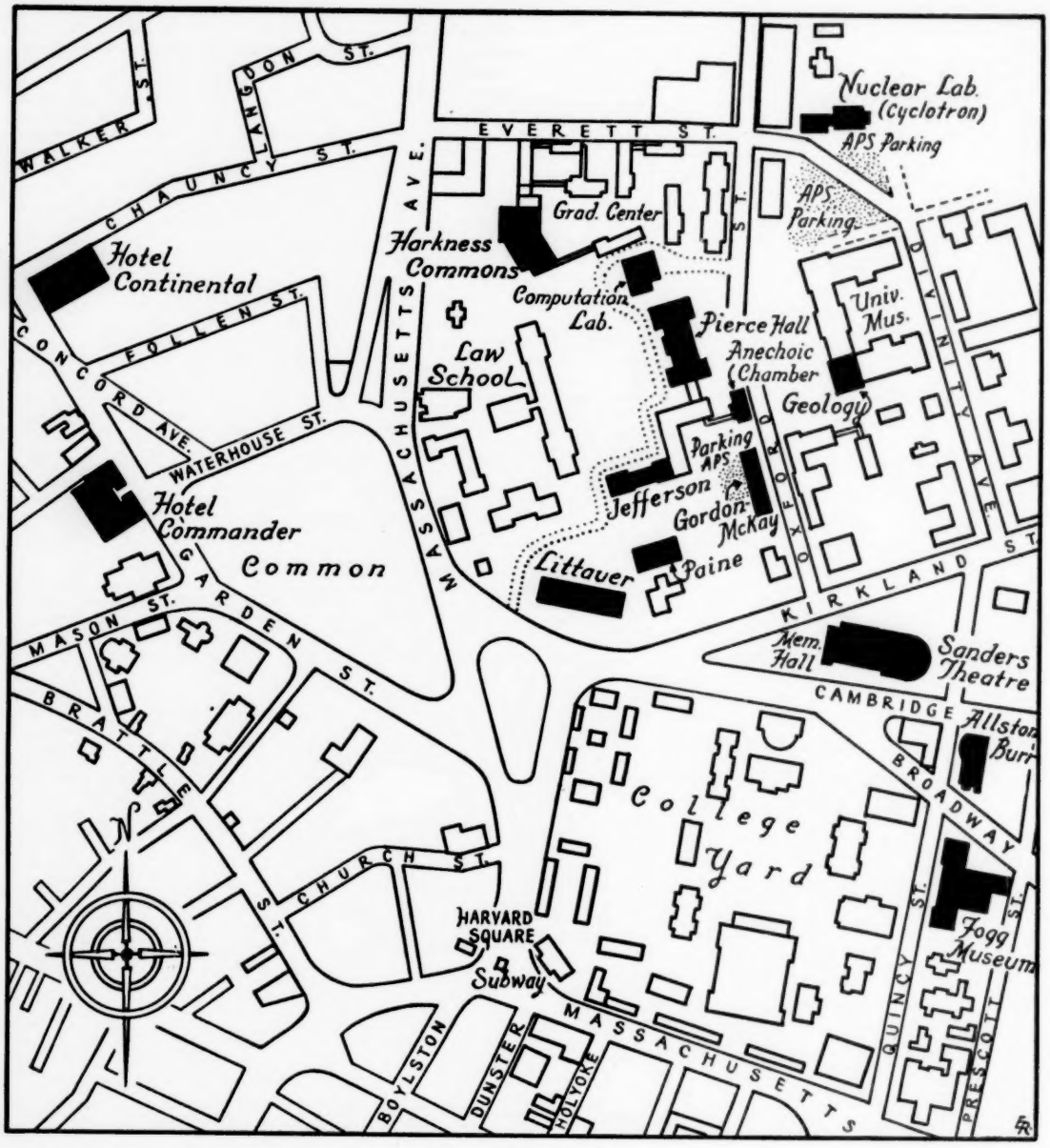
Storrs, C. L. and D. H. Frisch—C4
Sugarman, Nathan and Agnes Haber—D8
Sundaresan, M. K., E. E. Salpeter, and M. Ross—SA5
Sunyar, A. W.—Z3
Sutton, R. M.—P2
Tanaka, K.—JA11
Tchen, C. M.—U3
Temmer, G. M. and N. P. Heydenburg—C10
Tenney, F. and J. Tinlot—D5
Thickens, R. W. and R. J. MacDonald—T10
Thomson, Robb M. and Peter G. Bergmann—JA9
Tifford, Arthur N. and Sheng To Chu—U10
Tolhoek, H. A.—NA8
Toll, John S.—SA8
Trammell, G. T.—J3
Trefftz, Eleanor—VA6
Turkevich, A. and James B. Niday—D7
Turner, T. E., Verna C. Fiora, W. M. Kendrick, and B. L. Hicks—B4
Van Vleck, J. H.—P1
von Hippel, A., E. P. Gross, J. G. Jelatis, and M. Geller—N7
Wahlig, Charles F. and Park H. Miller—A11
Walker, William D.—G5
Waniek, R. W. and T. Ohtsuka—J9
Wanklyn, D. I.—W5
Watanabe, K., Edward C. Y. Inn, and Murray Zelikoff—K9
Wattenberg, A., B. T. Feld, and R. D. Godbole—W3
Weber, J.—JA10
Weil J. W. and B. D. McDaniel—W4
Weinreich, Gabriel and Vernon W. Hughes—UA2
Weisbaum, S., Y. Beers, and G. Herrmann—B6
Welton, T. A.—SA10

West, H. I. and L. G. Mann—S3
Weyl, Peter K.—UA8
Wheeler, John A. and David L. Hill—NA10
White, George R. and W. F. Fry—G6
Wilets, L., D. Hill, and K. W. Ford—NA12
Wilkinson, M. K. and C. G. Shull—T7
Williams, R. W. and W. E. Hazen—L8
Winsberg, Lester—D9
Wolfenstein, L.—SA2
Woonton, G. A.—Y1
Wu, C. S., F. Boehm, and E. Nagel—Z4
Yadoff, Oleg—Y13
Yergin, Paul F., Willis E. Lamb, Jr., Edgar Lipworth, and Robert Novick—UA1
Yevick, George J.—WA6
Zelikoff, Murray, Edward C. Y. Inn, and K. Watanabe—K10
Zimmerman, R. L., D. I. Cooper, and D. H. Frisch—C5
Zucker, Alexander—W1
Zucker, E. R., C. E. Mandeville, E. Shapiro, R. I. Mendenhall, and G. L. Conklin—Z1
Zucker, Francis J.—Y4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LYNDON ST.
CHAUNCY ST.
EVERETT ST.
Nuclear Lab.
(Cyclotron)
APS Parking
APS Parking
Grad. Center
Harkness Commons
Hotel Continental
FOLLEN ST.
CONCORD AVE.
WATERHOUSE ST.
MASSACHUSETTS AVE.
Computation Lab.
Pierce Hall
Anechoic Chamber
Univ. Mus.
Law School
Geology
Parking APS
Jefferson
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Hotel Commander
Common
Littauer
Paine
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GARDEN ST.
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Sanders Theatre
CAMBRIDGE
BRATTLE ST.
College Yard
BROADWAY
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